Fecal Coliform TMDL Development for Thumb Run, Virginia

Prepared by

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for

Virginia Department of Environmental Quality and
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EXECUTIVE SUMMARY

Background

The Thumb Run watershed is located in Fauquier County and is part of the Rappahannock River Basin. Thumb Run was listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998) due to violations of the State's water quality standard for fecal coliform. The Virginia Department of Environmental Quality (VADEQ) assessed the water quality of Thumb Run from July 1992 through July 1997. During this period, 47 percent of water quality samples collected exceeded the instantaneous water quality standard of 1,000 colony forming units (cfu) per 100 mL. The impaired segment of the stream is 7.4 miles long and extends from the confluence of West Branch Thumb Run and East Branch Thumb Run, downstream to its confluence with the Rappahannock River.

Based on Thumb Run's water quality impairment, the stream does not support its designated use of primary contact recreation (e.g. swimming and fishing). In order to meet its designated use, a Total Maximum Daily Load (TMDL) has been developed to meet the 30-day geometric mean fecal coliform standard of 200 cfu/100 mL.

Sources of Fecal Coliform

The potential fecal coliform sources in the watershed include both point and nonpoint sources. The Camp Moss Hollow Waste Water Treatment Plant (WWTP) (now off-line) was the only permitted point source to the stream. Nonpoint sources include livestock, wildlife, land application of biosolids, pets, straight pipes and failing septic systems. Bacterial source tracking (BST) samples collected in the watershed during the fall of 2001 verified that livestock, wildlife and humans are sources contributing to fecal coliform water quality standards violations in Thumb Run.

Modeling

The Hydrologic Simulation Program – Fortran (HSPF) was used to simulate existing conditions in the watershed and perform TMDL allocations. The BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) Version 3.0 interface was used to create, run and analyze results from the HSPF model. Seasonal variations in hydrology, climate, and watershed activities were accounted for in the model.

There is no available flow data for Thumb Run so hydrologic parameters were developed by modeling a reference watershed with available United States Geological Survey (USGS) flow data, the Battle Run watershed. The Thumb Run watershed and the Battle Run watershed have similar hydrologic characteristics including size, land-use, and soil types. The Battle Run hydrology was calibrated over a four-year period that included a range of hydrologic conditions. The calibrated model was then validated for a separate time period, and the calibrated parameters were applied to the Thumb Run watershed model.

The Thumb Run water quality model was then calibrated over a five-year period that included a significant amount of observed data. Five subwatersheds were delineated to better account for spatial variations of fecal coliform production in the watershed. The model adequately simulated the fate of fecal coliform in the watershed.

Existing Conditions

The in-stream fecal coliform concentration was determined by calculating several factors. Monthly fecal coliform loads to each landuse type were determined for each subwatershed based on information on the amount of fecal coliform produced in the different areas. Direct loads to the stream from livestock were determined on a seasonal basis. Direct and land-based loads from wildlife were estimated. Land-based loads from failing septic tanks and pets were estimated based on population. Fecal coliform die-off on the land surface and within the stream was accounted for.

Loads from all sources were represented in the HSPF model to establish existing conditions. The period from July 1997 to September 2001 was used to represent existing conditions. The model simulated existing conditions well and indicated violations of both the instantaneous and 30-day geometric mean standard.

Load Allocation Scenarios

Various load allocation scenarios were evaluated to enable Thumb Run to meet water quality standards. Existing loads were reduced in the Thumb Run HSPF model until fecal coliform concentrations in Thumb Run met the standards. A 5 percent margin of safety (MOS) was incorporated explicitly by reducing the water quality target from 200 cfu/ 100 mL to 190 cfu/ 100 mL. An allocation scenario was considered successful if the running 30-day geometric mean fecal coliform concentration never exceeded 190 cfu/100 mL.

Low flow periods were critical to the in-stream water quality. Reducing direct loads to the stream had the most significant impact on the improvement of water quality. Livestock account for 96 percent of the direct loads to the stream, so a reduction of livestock direct loads was included in all scenarios. Loads from straight pipes and failing septic systems were reduced 100 percent in all scenarios because state law prohibits untreated human waste from entering state waters.

The final load allocation scenario required a 100 percent reduction in direct loads from failing septic systems, in direct deposition to the stream from livestock, and in land-based loads from failing septic systems.

Recommendations for TMDL Implementation

Allocation scenarios created during the development of the Thumb Run TMDL provide a starting point for developing implementation strategies. The model indicates that low flow periods are the most critical for in-stream water quality conditions, so reducing direct loads to the stream should be prioritized in an implementation plan.

A scenario was developed that results in less than 10% violations of the instantaneous standard. This scenario can be used for transitional stage I implementation, where the most cost effective practices can be applied first. This type of staged implementation is an iterative process and is aimed at fostering local support for the implementation plan. Staged implementation allows for an assessment of the effectiveness of the proposed implementation plan and accuracy of the model. Adjustments can be made to the implementation plan if water quality monitoring during stage I implementation does not reflect expectations. The stage I allocation scenario requires 100 percent reduction in direct loads from the straight pipe and in land-based loads from failing septic systems, and 75 percent reduction of direct deposition to the stream from livestock. Stakeholder input is vital to the development of implementation plans to address the nonpoint source load reductions.

Public Participation

Public participation was sought throughout the development of the Thumb Run TMDL in order for watershed stakeholders to provide valuable input and receive updates on the TMDL progress. Three public meetings were organized, several newsletters were mailed out, and an informative website was created for this purpose (http://www.state.va.us/rrpdc/thumbrun/thumb_run.htm).

The first public meeting was held on August 1, 2001, to discuss the process for TMDL development. The second public meeting was held on November 8, 2001, to discuss the source assessment input, bacterial source tracking, and model calibration. The final public meeting was held on April 4, 2002, to discuss the draft TMDL report.

1. INTRODUCTION

1.1 Background

Section 303(d) of the Clean Water Act and the United States Environmental Protection Agency's (USEPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies which are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources (USEPA 1991).

1.2 Impairment Listing

Thumb Run was listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998) due to violations of the State's water quality standard for fecal coliform. Out of 15 samples collected during the 1998 assessment period on Thumb Run at the Route 770 bridge (river mile 4.69), 7 violated the water quality standard (47% violation rate). During the subsequent 2000 assessment period, 6 of 15 samples violated the water quality standard (40% violation rate).

Thumb Run is located in Fauquier County and is part of the Rappahannock River Basin (Figure 1.1). The 7.4 mile segment of Thumb Run from the confluence of West Branch Thumb Run and East Branch Thumb Run, downstream to its confluence with the Rappahannock River is impaired.

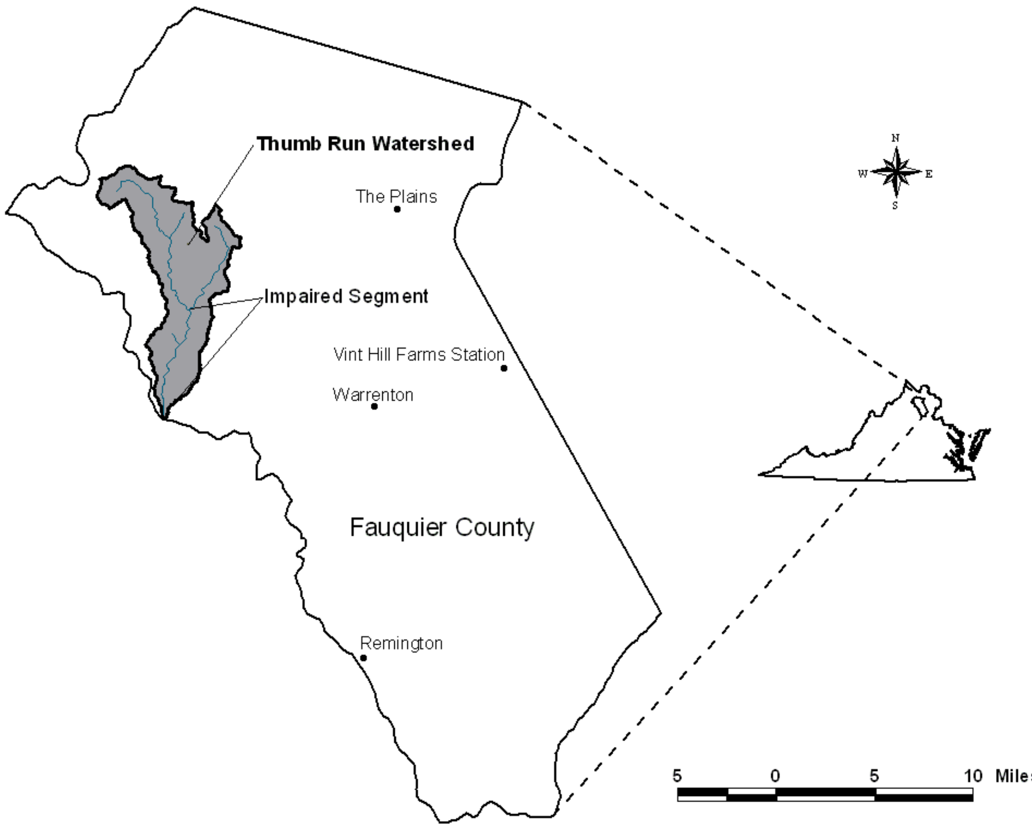


Figure 1.1. Location of the Thumb Run watershed.

1.3 Designated Uses and Applicable Water Quality Standard

According to Virginia Water Quality Standards (9 VAC 25-260-10), "all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)."

For a non-shellfish supporting waterbody to be in compliance with Virginia fecal coliform standards for contact recreational use, the Virginia Department of Environmental Quality (VADEQ) specifies the following criteria (9 VAC 25-260-170):

> "…the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 mL at any time."

If the waterbody exceeds either criterion more than 10 percent of the time, the waterbody is classified as impaired and a TMDL must be developed and implemented to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion is applied to a particular datum or data set (9 VAC 25-260-170). If the sampling frequency is one sample or less per 30 days, the instantaneous criterion is applied; for a higher sampling frequency, the geometric criterion is applied.

For Thumb Run the TMDL is required to meet the geometric mean criterion since the computer simulation gives daily fecal coliform concentrations, analogous to daily sample collection. The TMDL development process also must account for seasonal and annual variations in precipitation, flow, land-use, and pollutant contributions. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect fecal coliform loading.

1.3.1 Water Quality Standards Review

VADEQ and the Virginia Department of Conservation and Recreation (VADCR) have developed fecal coliform TMDLs for a number of impaired waters in the State. In some of the streams, fecal coliform bacteria counts contributed by wildlife result in standards violations, particularly during base flow conditions. Wildlife densities obtained from the Department of Game and Inland Fisheries and analysis or "typing" of the fecal coliform bacteria show that the high densities of muskrat, beaver, and waterfowl are responsible for the elevated fecal bacteria counts in these streams. In order to address this issue, the Commonwealth is currently reviewing its water quality standards with respect to fecal coliform bacteria. The issues under review are 1) designated uses, and 2) indicator species. Another option that USEPA allows for the states is to adopt site-specific criteria based on natural background levels of fecal coliform. The State must demonstrate that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs.

1.3.1.1 Designated Uses

All waters in the Commonwealth have been designated as "primary contact" for the swimming use regardless of size, depth, location, water quality or actual use. The fecal coliform bacteria standard is described in 9 VAC 25-260-170 and on page 1–3 in Section 1 of this report. This standard is to be met during all stream flow levels and was established to protect bathers from ingestion of potentially harmful bacteria. However, many headwater streams are small and shallow during base flow conditions when surface runoff has minimal influence on stream flow. Even in pools, these shallow streams do not allow full body immersion during periods of base flow. In larger streams, lack of public access often precludes the swimming use.

In the TMDL public participation process, the residents in these watersheds often report that "people do not swim in this stream.” It is obvious that many streams within the state are not used for recreational purposes. In many cases, insufficient depths of the streams as well as wildlife impacts prevent the attainment of the primary water quality standard.

Recognizing that all waters in the Commonwealth are not used extensively for swimming, Virginia is considering re-designation of the swimming use for secondary contact in cases of: 1) natural contamination by wildlife, 2) small stream size, and 3) lack of accessibility to children, as well as due to widespread socio-economic impacts resulting from the cost of improving a stream to a “swimmable” status.

The re-designation of the current swimming use in a stream will require the completion of a Use Attainability Analysis (UAA). A UAA is a structured scientific assessment of the factors affecting the attainment of the use that may include physical, chemical, biological, and economic factors as described in the Federal Regulations. The stakeholders in the watershed, Virginia, and USEPA will have an opportunity to comment on these special studies.

1.3.1.2 Indicator Species

USEPA has recommended that all States adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters by 2003. USEPA is pursuing the States' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and enterococci standard is scheduled for 2002 in Virginia.

1.3.2 Wildlife Contributions

In some streams for which TMDLs have been developed, even the removal of all of the sources of fecal coliform (other than wildlife) does not allow the stream to attain standards. TMDL allocation reductions of this magnitude are not realistic and do not meet USEPA's guidance for reasonable assurance. Based on the water quality modeling, many of these streams will not be able to attain standards without some reduction in wildlife. **Virginia and USEPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards.** This is obviously an impractical action. Clearly, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL or any other federal and state water quality management programs.

2. WATERSHED CHARACTERIZATION

2.1 Water Resources

The Thumb Run watershed contains approximately 23.2 miles of perennial streams (GIS analysis). The streams have trapezoidal channel cross-sections. The West Branch of Thumb Run extends for approximately 11.4 miles to the confluence with the main branch of Thumb Run. The main branch of Thumb Run originates in the northeast portion of the watershed and continues for approximately 4.4 miles to its confluence with the West Branch. For the purpose of this study, this segment is referred to as the East Branch of Thumb Run. Thumb Run then continues south 7.4 miles to its confluence with the Rappahannock River. Figure 2.1 shows the Thumb Run subwatersheds and stream network.

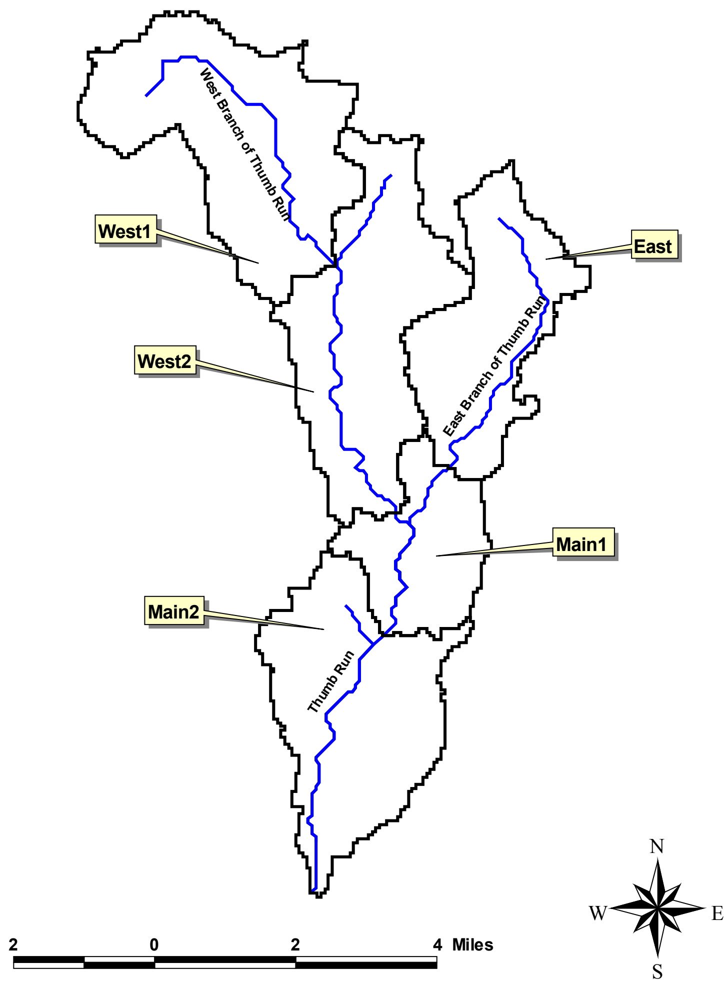


Figure 2.1 Thumb Run subwatersheds and stream network.

There is a small percentage of impervious surface in the watershed, resulting in relatively low contributions to the stream flow from surface runoff and high contributions from interflow and groundwater. The depth to the water table is greater than six feet (STATSGO database in BASINS: Kinerson et.al., 2001).

2.2 Soils, Geology, and Topography

The main soil classification in the watershed is class B consisting of Haysville, Parker, and Peaks soil types (STATSGO). These soils are well drained, with a high permeability of 2.85 in/hr (STATSGO). The soils are found on gently sloping to steep topography (STATSGO).

Figure 2.2 shows elevations in the watershed. The data shown is from USGS 300 Meter Resolution, 1-Degree Digital Elevation Models (DEM) for the hydrologic unit code (HUC) 02080103.

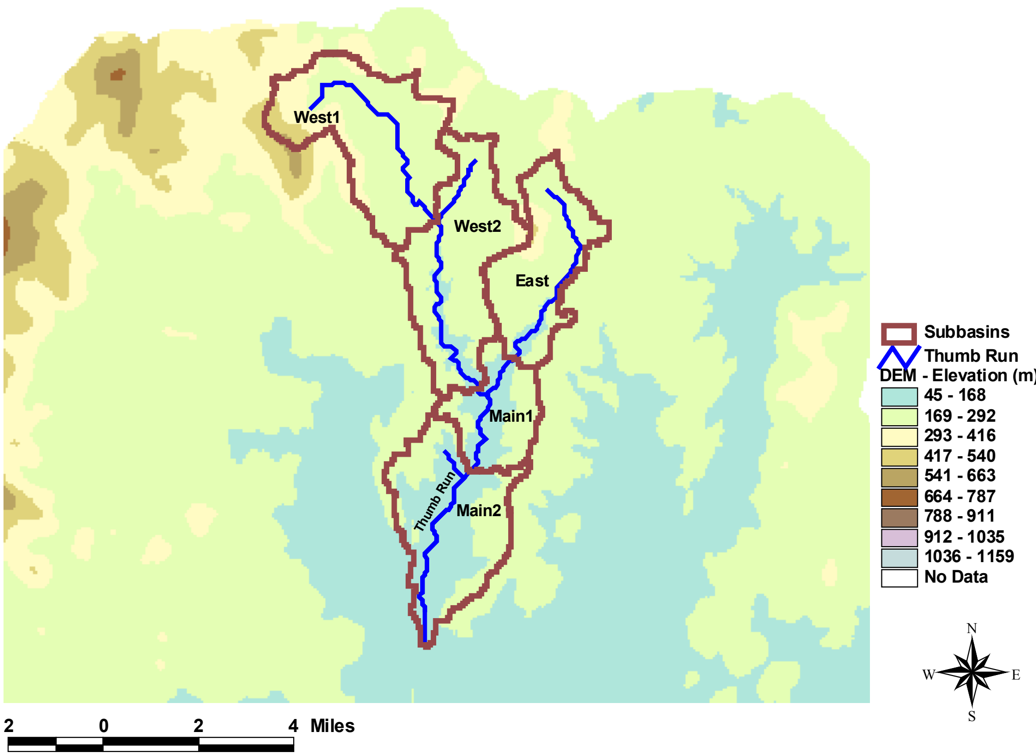


Figure 2.2 Elevation of the Thumb Run watershed.

2.3 Climate

The climate of the watershed is characterized based on the meteorological observations made by nearby National Weather Service cooperative stations and by observations made by local watershed residents. Climatic data was gathered from The Plains 2 NNE (38°54'N/77°45'W) located approximately 15 miles northeast of the Thumb Run watershed. The average annual precipitation is 42.12 in. and the average annual snowfall is 28.6 in. (SERCC, 2001). Supplemental climatic information was gathered from Washington Dulles Airport (38°56'N/77°26'51"W), located approximately 30 miles northeast of the Thumb Run watershed, and from the Piedmont Research Station (38°13'N/78°07'W), located approximately 40 miles south of the watershed. Several watershed residents recorded precipitation and weather conditions during rainfall events to supplement data used for water quality modeling.

2.4 Landuse

From 1995 aerial photographs, the Virginia Department of Conservation and Recreation identified twelve landuse types in the Thumb Run watershed. The twelve landuse types were grouped by similar hydrologic and waste production characteristics and then consolidated into seven TMDL landuse categories (Table 2.1).

Table 2.1. Consolidation of VADCR land use categories for Thumb Run watershed.

TMDL Landuse Categories	Percent Pervious	VADCR Landuse Categories (Class No.)
Cropland	100	Crop Land (211) Orchards, Groves, Vineyards (22)
Pasture 1	100	Improved Pasture/Permanent Hay (2121)
Pasture 2	100	Unimproved Pasture (2122) Grazed Woodland (461)
Farmstead	72	Farmstead (241)
Rural Residential	72	Low Density Residential (111)
Urban	75	Commercial (12) Transportation (14)
Forest	100	Forested (4) Harvested Forest Land (44) Water (5)

Landuse distribution in the five subwatersheds is presented in Table 2.2. Forest is the main landuse category, accounting for 49 percent of the total watershed area. Pasture1 is also a significant landuse, contributing 45 percent of the total area. Pasture2 accounts for 3 percent and cropland accounts for 2 percent of the total area. Residential/urban areas are nominal. Figure 2.3 displays the spatial variations of landuse within the subwatersheds.

Table 2.2. Landuse distribution in Thumb Run subwatersheds (acres).

Landuse	Subwatersheds					Total	
	West1	West2	East	Main1	Main2	Acres	%
Cropland	52	28	172	0	175	427	2.0
Pasture 1	1,973	2,939	2,004	1,000	1,960	9,876	45.4
Pasture 2	207	204	121	40	151	723	3.3
Farmstead	15	17	12	10	22	76	0.4
Rural Residential	5	11	7	4	26	53	0.2
Urban	0	0	0	0	3	3	0.0
Forest	3,424	1,902	1,385	1,349	2,558	10,618	48.8
Total	5,676	5,101	3,701	2,403	4,895	21,776	100.0

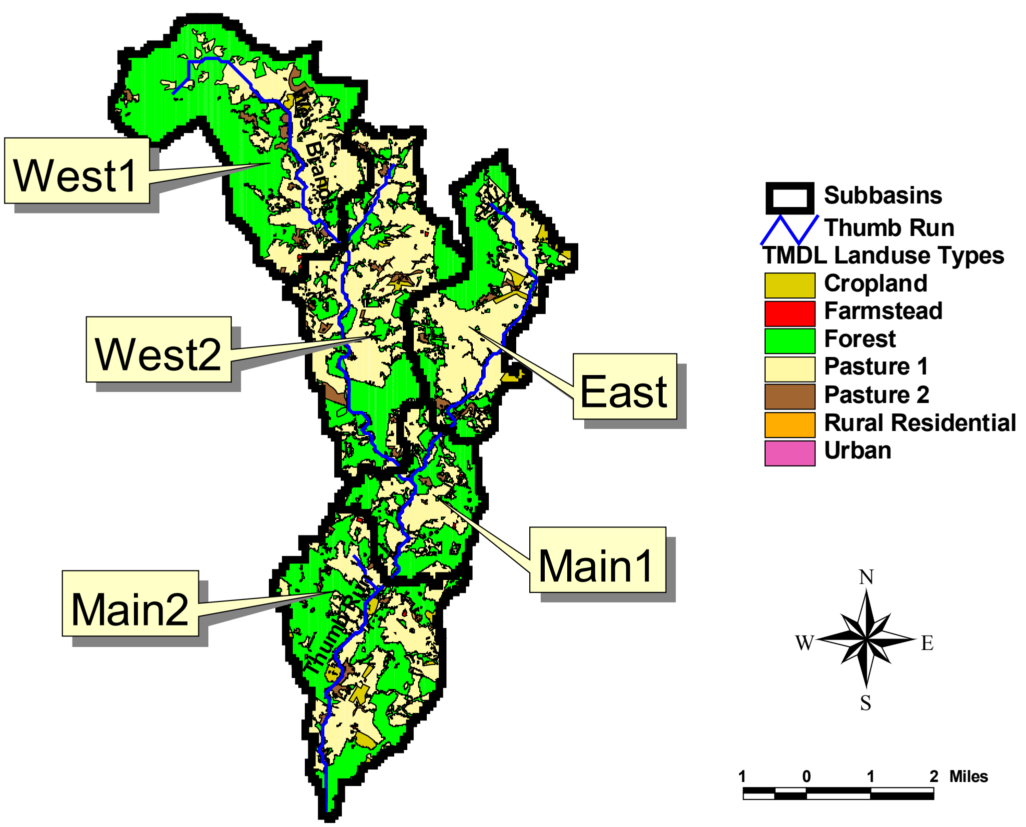


Figure 2.3 Landuse within the Thumb Run subwatersheds.

2.5 Population

There are an estimated 880 people residing within the watershed (2000 Census data). The population within each subwatershed was found using Fauquier County 2000 Census blocks obtained from TIGER/Line® files on the Internet (U.S. Census Bureau, 2001). The Census blocks were clipped in ArcView with the delineated subwatersheds. The percent of the Census block area that was within the subwatershed was multiplied by the total population in the block, giving the population within the block that was also within the subwatershed. Then the total population within the subwatershed was determined by summing the calculated populations from all blocks within the subwatershed, and rounding the sum. Figure 2.4 shows the calculated populations within each clipped block which were summed to find the subwatershed population.

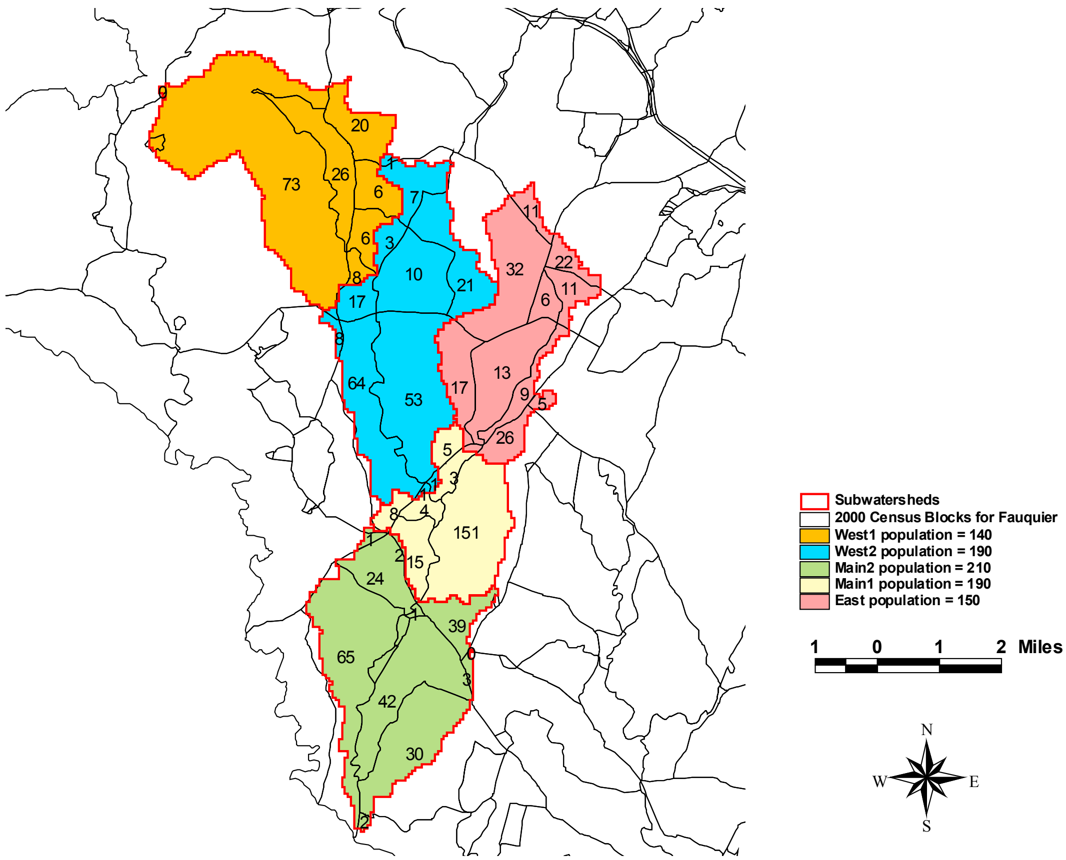


Figure 2.4 Subwatershed populations.

2.6 Water Quality Data

Various water quality monitoring data have been collected for the watershed. VADEQ has collected water quality samples from Thumb Run at three stations within the watershed and the Rappahannock-Rapidan Regional Commission (RRRC) has also collected samples at three sites (Figure 2.5).

2.6.1 DEQ Water Quality Monitoring Data

VADEQ has monitored the water quality of Thumb Run since 1991. Monitoring of fecal coliform has been performed on a quarterly basis since 1991 at a location below the confluence with the West Branch. Monitoring was performed monthly from July 1999 to June 2000 at two other locations, one on the West Branch and one on the East Branch, as part of a special study. The VADEQ monitoring locations are shown in Figure 2.5.

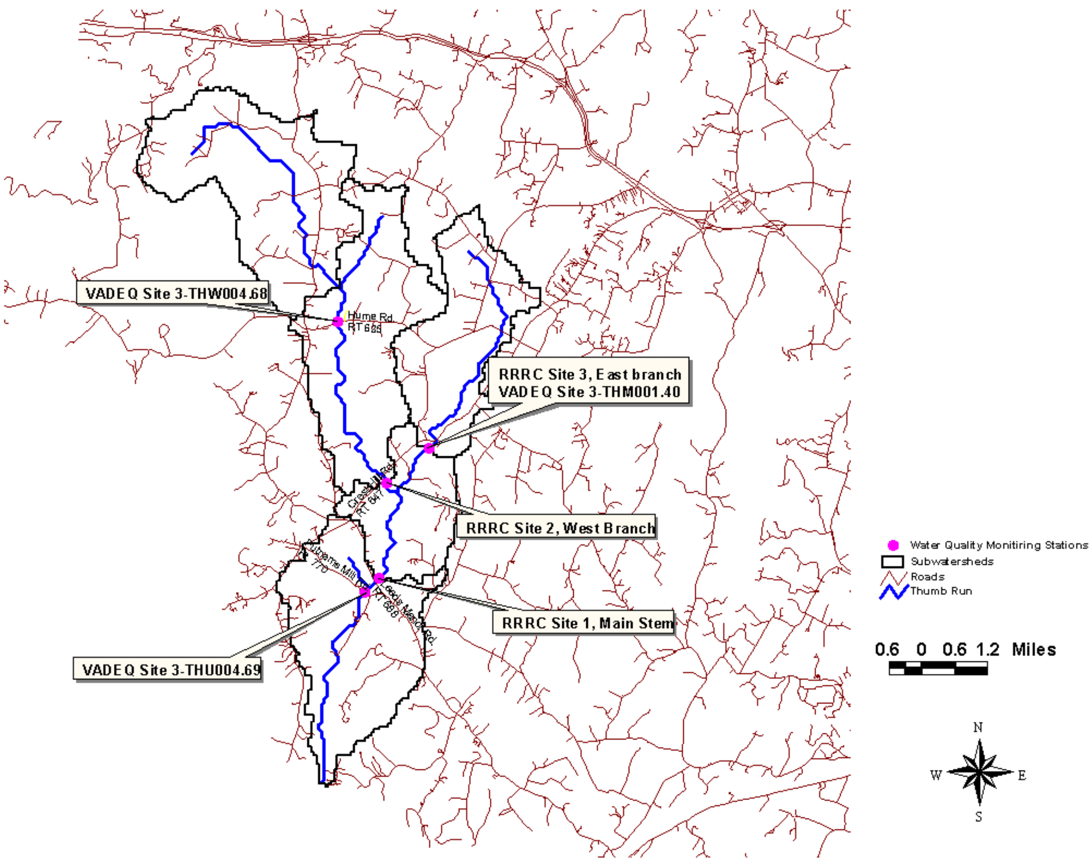


Figure 2.5 Thumb Run monitoring sites.

VADEQ analyzes the fecal coliform concentration in water samples by using the membrane filtration method. This method usually has a maximum detection limit of 8,000 cfu/100 mL, but can the limit can be increased to 16,000 cfu/100 mL if concentrations are expected to be high.

Monitored fecal coliform data from the VADEQ monitoring site 3-THU004.69 were used to list the stream as impaired. The assessment period for the 1998 303(d) report was between July 1992 and June 1998. Figure 2.6 shows the concentrations of fecal coliform during this time period. Of fifteen samples collected, seven exceeded Virginia's instantaneous standard, resulting in a 47 percent violation rate.

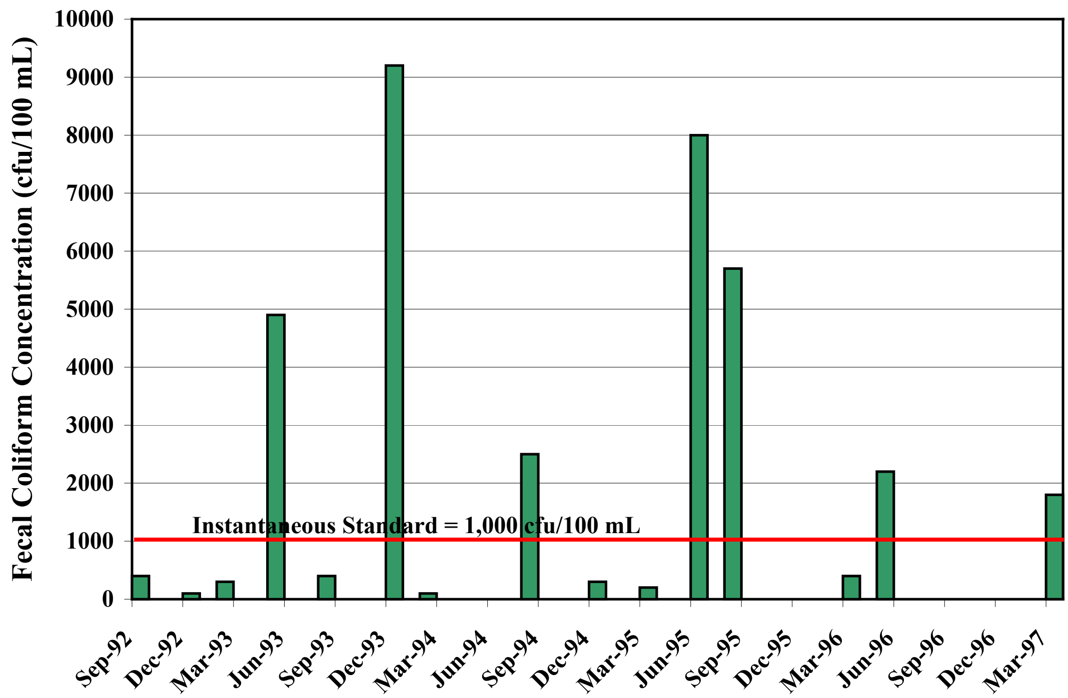


Figure 2.6 VADEQ monitoring for the 1998 assessment of Thumb Run.

2.6.2 RRRC Water Quality Monitoring Data

RRRC received a two-year §319 grant from VADCR in 2000 for the purpose of collecting water quality data for the development of a fecal coliform TMDL for Thumb Run. RRRC monitored three sites in the watershed from May 2000 to September 2001, on thirty-one separate dates. Monitoring sites were chosen at road crossings because they were easy to access and located on public land. One site was chosen on the West Branch of Thumb Run, another was chosen on the East Branch, and the third was chosen near VADEQ's monitoring site 3-THU004.69 (Table 2.5)

While monitoring, RRRC recorded field conditions including air temperature, water temperature, pH, and dissolved oxygen (DO). They also took a grab sample from the stream and sent it to a water quality laboratory. A quality assurance/quality control (QA/QC) plan was developed for the monitoring program to ensure that the samples were collected, processed and analyzed using USEPA approved procedures.

RRRC attempted to collect samples during both low and high flow critical conditions, or during dry or wet periods. A sample was considered to be a "dry" sample if there was no storm with more than 0.4 inches of precipitation within eight hours before monitoring, or one inch within the day before monitoring. A sample was considered to be a "wet" sample if there was a storm with more than 0.4 inches of precipitation within the eight hours before monitoring, or one inch within the day before monitoring.

Figure 2.7 shows fecal coliform results from monitoring during dry periods. Many of the samples exceeded the instantaneous standard and there seems to be a chronic problem at site 3 on the East Branch. Violations of standards during low flow periods are likely due to direct discharges to the stream such as point sources and animals in the stream. Levels are shown to be much higher in the summer months when livestock and wildlife might spend more time standing directly in the stream.

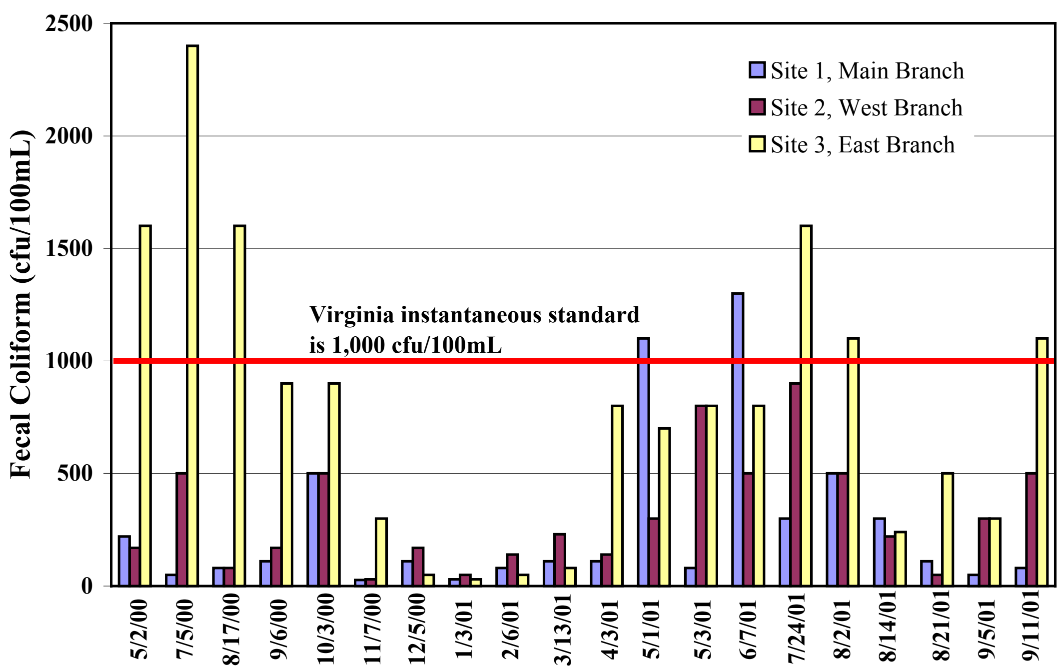


Figure 2.7 RRRC fecal coliform monitoring of Thumb Run during dry periods.

The samples taken during or within a day of a storm had significantly higher levels of fecal coliform (Figure 2.8). Many of these samples had levels that reached the maximum detection limit of the laboratory tests, 16,000 cfu/100 mL. High concentrations of fecal coliform during wet periods are likely due to land-based loads washed off to the stream with storm runoff.

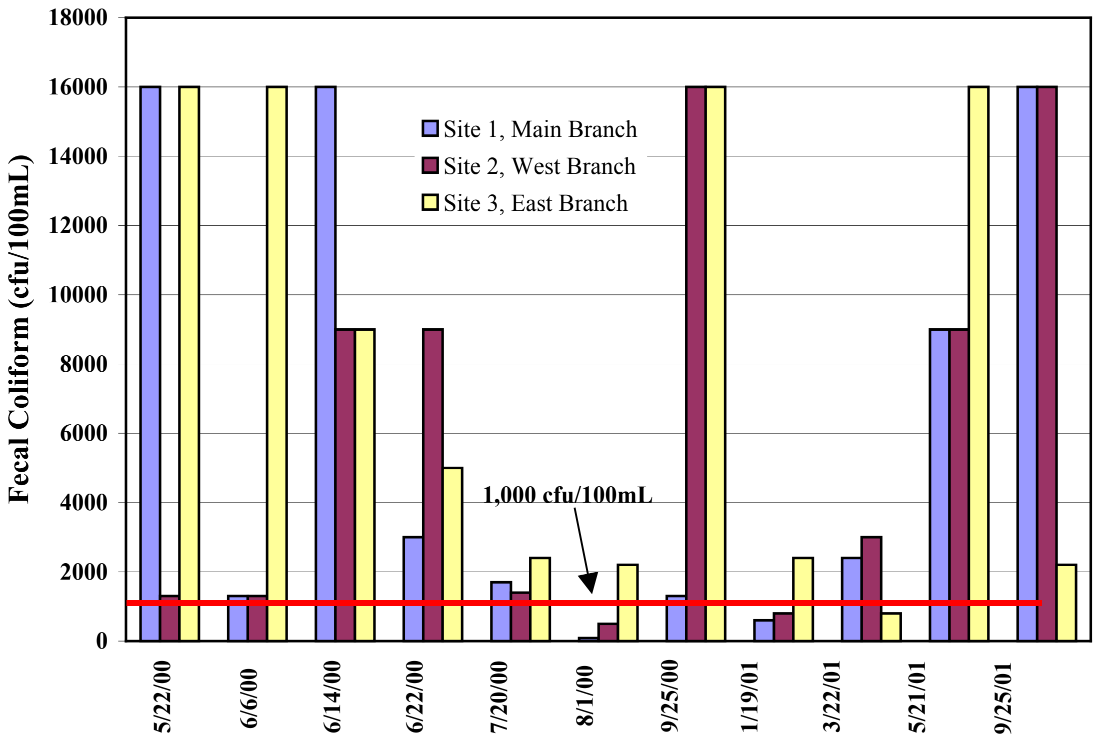


Figure 2.8 RRRC monitoring of Thumb Run during wet periods.

Table 2.3 lists average fecal coliform concentration and the number of instantaneous standard violations at each site monitored by RRRC.

Table 2.3. Summary of RRRC fecal coliform monitoring of Thumb Run

Site	Average FC Concentration During Dry Periods (cfu/100 mL)	Average FC Concentration During Wet Periods (cfu/100 mL)	Average FC Concentration During All Periods (cfu/100 mL)	Number of "Dry" Violations (out of 20)	Number of "Wet" Violations (out of 11)	Total Number of Violations (out of 31)
1 (Main)	262	6126	2343	2	9	11
2 (West)	313	6118	2373	0	9	9
3 (East)	793	8000	3350	6	10	16

3. SOURCE ASSESSMENT

A primary component of the fecal coliform Total Maximum Daily Load (TMDL) development for Thumb Run is the evaluation of potential sources of fecal coliform in the watershed. Sources of information that were used in evaluating potential pollutant sources include the Virginia Department of Environmental Quality (VADEQ), the Virginia Department of Conservation and Recreation (VADCR), the Virginia Department of Game and Inland Fisheries (VADGIF), the Virginia Department of Health (VDH), public participation, watershed studies, stream monitoring, published information, previously approved fecal coliform TMDLs, and best professional judgment.

The potential fecal coliform sources in the watershed can be broken down into point and nonpoint sources. Point sources are permitted pollutant loads derived from individual sources and discharged at specific locations. Nonpoint sources develop from various sources over a relatively large land area. The following sections describe potential point and nonpoint sources within the watershed.

3.1 Assessment of Point Sources

One point source was permitted to discharge into the Thumb Run watershed through the Virginia Pollution Discharge Elimination System (VPDES). The Camp Moss Hollow Wastewater Treatment Plant was permitted under VPDES permit number VA0060976, which expired on September 30, 2001.

The plant is located in the northwest portion of the watershed, as shown in Figure 3.1. The design flow for this facility is 0.01 million gallons per day. The allowable fecal coliform concentration in the discharge is 200 cfu/100 mL. The wastewater treatment plant was last inspected on August 16, 2000, and found to be off-line and replaced by a septic system (Thomas, 2001a).

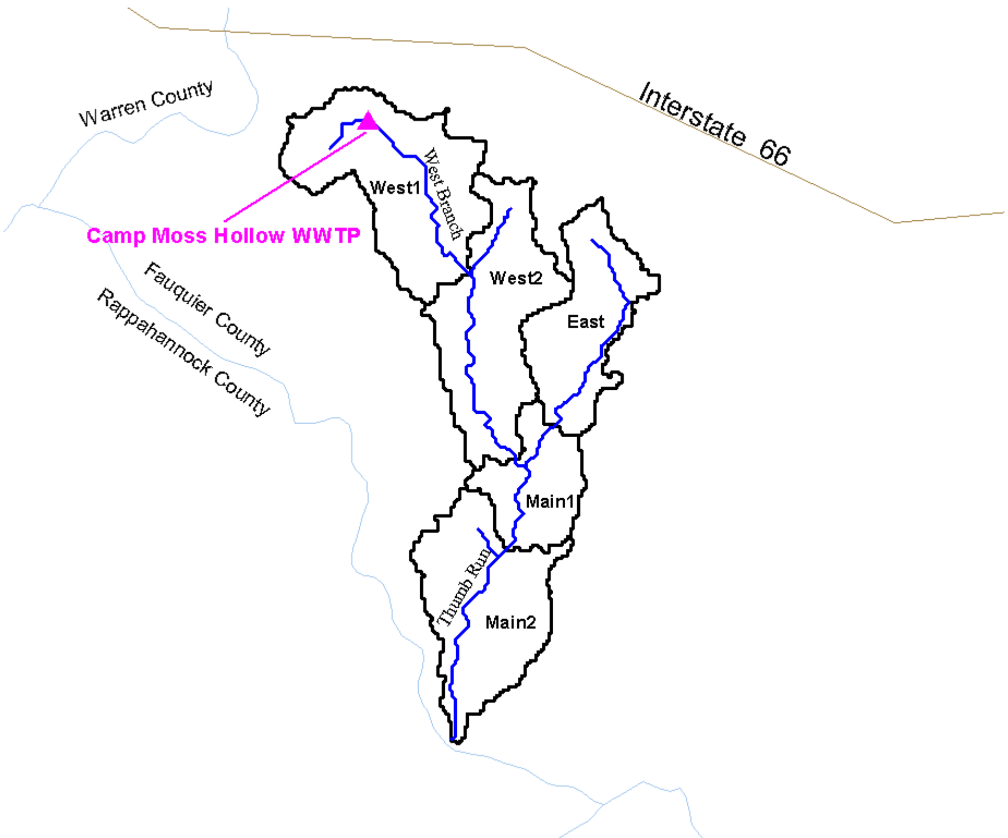


Figure 3.1. Thumb Run subwatersheds and point source discharges.

No uncontrolled point source discharges are known to exist along Thumb Run. The Rappahannock Conservation Council, the John Marshall Soil and Water Conservation Districts, and several volunteers performed an impaired stream assessment survey of Thumb Run in December 1999 (RCC, 1999). Their stream evaluation consisted of a stream walk where all potential environmental problems were identified and documented: no pipe outfalls that could carry uncontrolled runoff and pollutants into the stream were found. The same field evaluation also sought to identify exposed pipes along Thumb Run that could be damaged by a high flow event – again, none were found.

Privately owned VPDES permits are issued by the VADEQ under the General VPDES Permit for Domestic Sewage Discharges of Less than or Equal to 1,000 Gallons per Day (VAG40). These permits are issued to single-family homeowners to treat domestic wastewater and release the treated effluent to state waters. VADEQ reports that, at time of writing, there are no single-family home discharges permitted within the Thumb Run watershed (Thomas, 2001b).

3.2 Assessment of Nonpoint Sources

3.2.1 Livestock Inventory

Personnel from RRRC and VADCR conducted a windshield survey of livestock in the Thumb Run watershed on October 19, 2000. Local producers verified livestock numbers estimated from this survey.

There are several cattle, horse, and sheep farms within the watershed, as well as a kennel. Estimated livestock totals for the watershed include 1,700 cattle, 200 horses, 150 sheep, and 100 hounds. The livestock inventory for the watershed is summarized in Table 3.1.

Table 3.1. Summary of estimated livestock population.

	Cattle	Horses	Sheep	Hounds
Population[1]	1,700	200	150	100
Average Weight (lbs)	1,000[1]	1,000[2]	60[2]	60[3]
Equivalent Animal Units[4] (AU)	1,700	200	9	6

[1] Estimated value, based on windshield survey and anecdotal information from local producers
[2] MapTech, 2000: Maggodee Creek TMDL
[3] The average weight of a hound is assumed to be equal to that of a sheep.
[4] Animal Units equal population multiplied by average weight and divided by 1,000 pounds

Jay Marshall, VADCR, consulted local producers and determined the livestock populations within each subwatershed (Table 3.2).

Table 3.2. Estimated livestock populations within Thumb Run subwatersheds.

Thumb Run Subwatershed	Cattle	Horses	Sheep	Hounds
West1	300	40	0	0
West2	400	40	0	40
East	450	40	0	0
Main1	210	30	0	0
Main2	340	50	150	60
Total	1,700	200	150	100

There are several pathways by which fecal coliform produced by livestock can enter surface waters. Local producers state that livestock are never confined within the watershed, therefore, animal waste is not collected and applied to the land. Two pathways are then possible: through rainfall wash-off of manure deposited directly on the land, and through manure deposited directly in the streams.

Based on the findings of previous fecal coliform TMDLs for Virginia and discussions with VADCR and local producers, the following assumptions were used to estimate livestock population and manure distribution among landuse types and the stream.

1. Livestock remain within “grazing” areas defined by the TMDL landuse categories pasture 1 (improved pasture) and pasture 2 (unimproved pasture/grazed woodlands). Pasture 2 stocks twice as many livestock per acre as pasture 1 (BSE, 2000a).
2. Hounds remain in “grazing” areas 100 percent of the time.
3. Seventy percent of “grazing” areas provide cattle and sheep with stream access and 50percent of “grazing” areas provide horses with stream access (Marshall, 2001).
4. Cows with access to the stream spend four percent of their time in the stream in December, January, and February; six percent in March, October, and November; eight percent in April, May, and September; and ten percent in June, July, and August (MapTech, 2001) (Table 3.3).

Table 3.3. Average time cattle spend in different areas per day (MapTech, 2001).

Month	Pasture (hr)	Stream Access (hr)
January	23.0	1.0
February	23.0	1.0
March	22.5	1.5
April	22.0	2.0
May	22.0	2.0
June	21.5	2.5
July	21.5	2.5
August	21.5	2.5
September	22.0	2.0
October	22.5	1.5
November	22.5	1.5
December	23.0	1.0

5. The time that horses with access to the stream spend in the stream is twenty-five percent of the time that cattle spend in the stream (Marshall, 2001).
6. The time that sheep with access to the stream spend in the stream is ten percent of the time that cattle spend in the stream (Marshall, 2002).
7. Thirty percent of livestock in the stream defecate in the stream (BSE, 2000a). Fecal coliform deposited directly in the stream is modeled as a direct source loading.
8. Livestock not directly defecating in the stream are defecating on “grazing” areas. Fecal coliform deposited on “grazing” areas is modeled as a land loading.

A sample calculation of the distribution of livestock is provided in Appendix E.

3.2.2 Septic Systems and Straight Pipes

Septic systems, if improperly installed and maintained, are a potential source of fecal coliform in the Thumb Run watershed. There is no detailed information available on specific septic system locations, numbers, or failure rates. However, RRRC estimated the number of septic tanks within the watershed by evaluating US Census data, and verified the numbers by performing a windshield survey and checking E-911 records of residences within the watershed.

2000 Census data indicates a population of 880 people living in the watershed. Applying an average occupancy rate of 2.75 people per residence (2000 Census data for Fauquier County) and assuming that each residence has a septic system, this method estimates that there are 320 residences with septic systems located in the watershed.

Based on a 1973 County ordinance that prohibited septic system installation closer than 50 feet to streams, and given the general assessment that soils within the watershed are suitable for installing a septic system, VDH estimates that five percent of the septic systems located within the watershed are both failing ***and*** close enough to streams to contribute fecal coliform loads (Largent, 2001). For the remainder of this document, septic systems that have the potential to contribute fecal coliform to the stream (i.e., those that are failing and are located within 50 feet of a stream) are collectively defined as “failing septic systems”.

Using VDH’s estimated “failure” rate of five percent and the estimate of 320 septic systems, it is estimated that there are 16 failing septic systems within the watershed. The contribution of these systems will be modeled as land loads, washed off to the receiving waters during storm events.

Based on available literature, each person residing within the watershed is estimated to produce 1.95×10^9 cfu/day of fecal coliform (Geldreich et al., 1978). Multiplying this rate by the estimated average occupancy rate in the watershed (2.75 people per residence) provides an estimated total fecal coliform loading to the land of 5.36×10^9 cfu/day from each failing septic system.

The total number of failing septic systems was distributed proportionally to each subwatershed based on population density (BSE, 2000b). The distribution of failing septic systems within each subwatershed is shown in Table 3.4.

Table 3.4. Estimated number of failing septic systems and straight pipes in each Thumb Run subwatershed.

Thumb Run Subwatershed	Population (2000 Census)	Total Number of Septic Systems	Failing Septic Systems	Straight Pipes
West1	140	51	3	1
West2	190	69	3	-
East1	150	55	3	-
Main1	190	69	3	-
Main2	210	76	4	-
Total	880	320	16	1

One home within the West1 subwatershed is known to be very close to Thumb Run. For conservative purposes, this home is assumed to have a failing septic system that acts as a straight pipe, directly contributing fecal coliform to the stream.

3.2.3 Wildlife Inventory

The total contribution of fecal coliform from wildlife is unknown. However, the VDGIF, RRRC, and watershed residents indicate that there is a significant natural wildlife population within the Thumb Run watershed. Specific wildlife species known to exist in the watershed and suspected of contributing significant quantities of fecal coliform include deer, duck, wild turkey, geese, muskrat, raccoon, beaver, fox, and bear. VDGIF provided this assessment with population estimates for wild turkey, beaver, fox, and bear. Other wildlife populations were calculated from the estimated area of suitable habitat for each target species and estimates of population density for each defined suitable habitat.

Suitable habitats for various wildlife species were defined through consultation with VDGIF, watershed residents, field observation, and similar estimates prepared for other approved Fecal Coliform TMDLs. Each suitable habitat was then spatially generated and measured using GIS. Definitions for suitable habitat areas for individual wildlife species are as follows:

- Deer: all forested, cropland, and pasture areas (this suitable habitat is assumed for fox and bear as well);
- Duck: all forested, cropland, and pasture areas within 400 meters of perennial streams;
- Turkey: all forested areas;
- Goose: all forested, cropland, and pasture areas within 100 meters of surface water impoundments;

- Muskrat: all forested area within 10 meters of perennial streams;
- Raccoon: all forested, cropland, and rural residential areas within 400 meters of perennial streams;
- Beaver: all forested, cropland, and pasture areas within 100 meters of perennial stream.

Estimated population densities for wildlife species living within the defined suitable habitat areas were derived using information from the following sources:

- Deer: Knox, 2000 (42 deer/square mile of habitat);
- Duck: BSE, 2001;
- Turkey: MapTech, 2001;
- Goose: BSE, 2001;
- Muskrat: BSE, 2001;
- Raccoon: Giles, 1992;
- Beaver: MapTech, 2001;
- Fox: Calculated from given population divided by suitable habitat;
- Bear: Calculated from given population divided by suitable habitat.

Information used to estimate the fecal coliform contributions from significant wildlife populations residing within the watershed are summarized in Table 3.5.

Table 3.5. Wildlife summary.

	Deer	Duck	Turkey	Goose	Muskrat	Raccoon	Beaver	Fox	Bear
Population Density (#/acre)	0.0656[1]	0.04[2]	0.01[9]	0.455[2]	5[2]	0.07692[2]	0.0317[9]	0.0106[10]	4.6e-4[10]
Suitable Habitat (acres)[3]	21,644	6,703	10,618	1,547	13	2,608	3,281	21,644	21,644
Population	1420	268	106	704	64	201	104[1]	230[1]	10[11]
Average Weight (lbs)	120[8]	2.5[4]	11[5]	10[4]	2.5[6]	15[6]	45[6]	15[7]	315[7]
Animal Units, AU	209	1	1	7	0	3	5	3	3

(population numbers might not add up due to rounding)
1 The Virginia Department of Game and Inland Fisheries (VDGIF)
2 BSE, 2001
3 Derived from GIS manipulation with VADCR landuse, defined by VDGIF
4 PGC, 2001
5 ASAE, 1998
6 INHS, 2001
7 Bear Country U.S.A., 2001
8 Pommer, 2001
9 MapTech, 2001
10 Calculated from given population/suitable habitat
11 Bear population estimated from consultation with VDGIF and watershed residents

Estimated total wildlife populations were allocated proportionally to each subwatershed according to suitable habitat area, except for bear, which are found only within subwatersheds West1 and West2 (communication with watershed residents). Table 3.6 presents these distributions.

Table 3.6. Estimated wildlife populations per Thumb Run subwatershed.

Thumb Run Subwatershed	Deer	Duck	Turkey	Goose	Muskrat	Raccoon	Beaver	Fox	Bear
West1	368	70	34	183	21	52	27	60	6
West2	335	63	19	165	11	47	24	54	4
East1	238	45	14	120	8	34	18	39	0
Main1	158	30	13	78	8	22	11	25	0
Main2	321	60	26	158	15	45	23	52	0
Total	1420	268	106	704	64	201	104	230	10

(totals might not add up due to rounding)

The percentage of wildlife defecating in the stream each day is based on the habitat and characteristics of the individual wildlife species. Table 3.7 displays the estimated time that each species spends in the stream (MapTech, 2001) and the estimated portion of the animals that are in the stream that are defecating in the stream (professional judgment).

Table 3.7. Portion of the day that wildlife spend in the stream and the portion in the stream that are defecating.

Wildlife Species	Portion of the Day Spent In and Around the Stream (%)	Portion of Population in and Around the Stream that are Defecating in the Stream (%)
Deer	5	25
Duck	75	75
Turkey	5	25
Goose	50	50
Muskrat	90	90
Raccoon	5	25
Beaver	100	100
Fox	5	25
Bear	5	25

3.2.4 Pets

Pet waste can contribute to fecal coliform loadings in streams by washing off from residential areas during runoff producing rainfall events. For the purpose of this study, pet waste is only considered as feces from cats and dogs, the predominant pets in the watershed. There are an estimated 320 pets in the Thumb Run watershed, assuming one pet per household (BSE, 2000: Dry River TMDL). Pet waste is assumed to be generated on land surfaces solely within the rural residential and farmstead landuse types. Pets are estimated to produce 0.45×10^9 cfu/day (Weiskel et al., 1996).

The estimated pet population within each sub-watershed, based on the area of rural residential and farmstead landuse within each subwatershed, is shown in Table 3.8.

Table 3.8. Estimated population of pets in each Thumb Run subwatershed.

Thumb Run Subwatershed	% of Total Rural Residential and Farmstead Landuse in Subwatershed	Pets
West1	15	50
West2	22	71
East	15	47
Main1	11	35
Main2	37	118
Total	100	320

3.2.5 Biosolids Application

The Virginia Department of Health (VDH) permits biosolids produced by wastewater treatment plants to be applied to agricultural land in the state. VDH regulates how the biosolids are applied, requiring that biosolids be spread according to sound agronomic practices that consider topography and hydrology. Class B biosolids are required to have a fecal coliform density of less than two million cfu (or MPN) per gram of biosolids (see 40 CFR 503.32(b)(2)).

VDH has identified three properties within the watershed that are permitted to apply biosolids (Lopasic, 2001). The total permitted area for biosolids application in the watershed is 510 acres. The properties receive biosolids from the Blue Plains Waste Water Treatment Plant.

These properties are permitted to receive a maximum of five dry tons of biosolids per acre over a three-year period. A record of biosolids application within the watershed was investigated, and only one property was found for which VDH records document that biosolids were applied during the water quality calibration time period (Lunsford, 2001b). The property applied the biosolids over a three day period.

The geometric mean fecal coliform density in biosolids from the Blue Plains Waste Water Treatment Plant for the month biosolids were applied was 1,246 cfu/g (Lunsford, 2001a).

The fecal coliform contribution from the biosolids was modeled as a direct source in the East subwatershed on the date of the first significant storm after the application. This methodology is described further in Section 4.4.1.4.1.

3.3 Bacterial Source Tracking

Bacterial Source Tracking (BST) is a new methodology being used to determine the sources of fecal bacteria in environmental samples. BST is considered an experimental tool, yet a useful one to diagnose fecal coliform sources.

BST was performed by James Madison University (JMU) to confirm the presence of suspected sources of fecal coliform in Thumb Run and confirm literature values that have been used in this assessment. A report of JMU's findings is attached as Appendix D.

The regional commission collected seven stream samples on different dates from each of the three monitoring sites, and sent them to JMU for bacteria isolation analysis. They also collected thirty fecal samples from five known sources that were considered to be possible significant fecal coliform contributors (cattle, deer, geese, horses, and humans) and three fecal samples from unknown sources. The samples were collected from various locations throughout the watershed. A total of thirty-three fecal matter samples were collected as follows:

- Five samples from cattle;
- Six samples from deer;
- Five samples from geese;
- Six samples from horses;
- Eight samples from humans; and
- Three samples from unknown sources.

All sources of fecal coliform could not be included in the BST analysis. Sources were chosen for the analysis based on the information available in JMU's indicator bacteria library, pollutant significance estimated by the source's population and accessibility to streams, and the feasibility of collecting a fecal sample. Sheep were not included in the analysis because of their low population and limited access to the stream. Hounds were not included because they have no access to the stream. Many wildlife species were not included because data was not available in the indicator library or their waste samples could not be found.

JMU used Antibiotic Resistance Analysis (ARA), a method of comparing the antibotic resistance patterns of isolated bacteria taken from water samples to the resistance patterns of isolated indicator bacteria taken from known fecal samples. JMU used two different ARA techniques, one where enterococci (ENT) are isolated as indicator bacteria and one where fecal coliforms (FC) are isolated as indicator bacteria. The two techniques produced different results. The results from the ENT analysis were considered more accurate because the average rate of correct classification of the ENT library was much higher than that for the FC library.

There are two significant limitations of the BST methodology used for this study. Sampling took place over only a two month period, so the results do not show seasonal variations. Also, only one sample was taken after a significant amount of rainfall, therefore the sampling period represents predominantly baseflow conditions during which direct sources, such as straight pipes or direct deposition of manure in the stream, are major contributors.

Some general conclusions were made from the BST analysis in order to aid in estimating the fecal coliform loadings from various sources, calibrating the model, and performing the allocation scenarios. Cattle, wildlife, and human waste was present throughout the watershed. Geese were found to be a prominent wildlife source in the West Branch. Humans are known to be a source at all three stations. Horses were only a minor source.

3.4. Summary of Potential Fecal Coliform Sources

The fecal coliform concentrations in Thumb Run can be attributed primarily to nonpoint sources including human, wildlife, and livestock. The BST analysis confirmed that the fecal coliform in Thumb Run can be traced to many of these potential sources. Table 3.9 summarizes all potential fecal coliform sources in the Thumb Run watershed.

Table 3.9. Summary of potential fecal coliform contributors to Thumb Run.

Fecal Coliform Source			Population	Average Weight (lbs)[6]	Animal Units, AU (1000 lbs)	Daily Feces Production (g/AU)	Fecal Coliform Density (cfu/g)	Daily Fecal Coliform Production (cfu/AU)	Individual Fecal Coliform Production (cfu/day)	Watershed Fecal Coliform Production (cfu/day)[21]
Nonpoint	Livestock	Cattle	1,700[1]	1,000	1,700	18,144[7]	1.14E+6[7]	20.7E+9[13]	20.7E+9	35.3E+12
Nonpoint	Livestock	Horse	200[1]	1,000	200	-	-	0.420E+9[18]	0.420E+9[12]	84.0E+9
Nonpoint	Livestock	Sheep	150[1]	60	9	-	-	0.200E+12[18]	12.0E+9[12]	1.80E+12
Nonpoint	Livestock	Hound	100[1]	60	6	-	-	83.3E+9[18]	5.00+9[19]	0.500E+12
Nonpoint	Wildlife	Deer	1420[2]	120	170	772[7]	0.450E+6[7]	0.347E+9[13]	41.7E+6	62.1E+9
Nonpoint	Wildlife	Duck	268[2]	2.5	1	-	-	48.0E+9[18]	2.50E+9[20]	32.2E+9
Nonpoint	Wildlife	Turkey	106[2]	11	1	-	-	8.64E+9[18]	9.50E+7[12]	10.1E+9
Nonpoint	Wildlife	Goose	704[2]	10	7	163[7]	0.800E+6[7]	0.130E+9[13]	1.30E+6	0.918E+9
Nonpoint	Wildlife	Muskrat	64[2]	2.5	0	100[7]	0.250E+6[7]	25.0E+6[13]	62.5E+3	3.98E+6
Nonpoint	Wildlife	Raccoon	201[2]	15	3	450[7]	0.250E+6[7]	0.113E+9[13]	1.69E+6	0.339E+9
Nonpoint	Wildlife	Beaver	104[2]	45	5	450[9]	0.250E+6[9]	0.113E+9[13]	5.06E+6	0.528E+9
Nonpoint	Wildlife	Fox	230[2]	15	3	-	-	0.338E+9[13]	5.06E+6[10]	1.16E+9
Nonpoint	Wildlife	Bear	10[3]	315	3	-	-	0.132E+9[13]	41.7E+9[11]	0.417E+9
Nonpoint	Other	Pets	320[4]	-	-	-	-	-	0.450E+9[14]	0.144E+12
Nonpoint	Other	Failing Septic System	16[5]	-	-	-	-	-	5.36E+9[15]	85.8E+9
Nonpoint	Other	Biosolids Application	-	-	-	-	-	-	-	0.53E+12[16]
Nonpoint	Other	Straight Pipe	1[17]	-	-	-	-	-	5.36E+9[15]	5.36E+9
Point		CMH WWTP	-	-	-	-	-			7.57E+9

1 Windshield survey by Karen Henderson-Taubenberger (RRRC) and Jay Marshall (VADCR, local producer)
2 Generated from GIS manipulation with VADCR landuse and suitable habitat defined by VDGIF
3 The Virginia Department of Game and Inland Fisheries (VDGIF)
4 BSE, 2000b
5 2000 Census, Virginia Department of Health (VDH)
6 See Table 1 and 5
7 BSE, 2001
8 PSU, 2001
9 Daily feces production values for beaver are assumed to be the same as those for raccoon.
10 Individual FC production values for fox are assumed to be same as that for a beaver.
11 Individual FC production values for bear are assumed to be same as that for a deer.
12 ASCE, 1998.
13 Calculated by multiplying fecal coliform density by daily feces production
14 Weiskel et al., 1996
15 Geldreich et al., 1978
16 Biosolids application is not a continuous source. It was modeled as a point source load on one day within the water quality calibration time period
17 This is an assumption based on the proximity of one home to the stream
18 Calculated by multiplying individual FC production by population and dividing by AU.
19 Horsly and Witten, 1996.
20 Roll and Fujioka, 1995.
21 Calculated by multiplying individual FC production by population (except for WWTP and biosolids).

4. MODELING PROCEDURE

An essential component in developing a TMDL is to establish a relationship between the point and nonpoint source loadings and the in-stream water quality. This relationship allows management options to be evaluated that will reduce pollutant loadings in a waterbody so that the waterbody can support its designated use. In developing a TMDL for the Thumb Run watershed, this relationship was established by using several tools including computer simulation models, monitoring data, and geographic information systems (GIS). In this section, the model procedure, required inputs, calibration and validation, and results are discussed.

4.1 Model Description

The Hydrological Simulation Program-Fortran (HSPF) Release 12 watershed model (Bicknell et al., 2000) was selected to simulate hydrology and water quality in the Thumb Run watershed. HSPF continuously simulates hydrologic and water quality processes occurring on pervious (PERLND module) and imperious (IMPLND module) land segments and in the stream (RCHRES module). Hydrologic processes are simulated for pervious and impervious land segments through the PWATER and IWATER sub-modules respectively, and in the stream network through the HYDR and ADCALC sub-modules. The fate and transport of pollutants on pervious and impervious surfaces are simulated through the PQUAL and IQUAL sub-modules respectively. The fate of pollutants in the stream is simulated through the GQUAL sub-module.

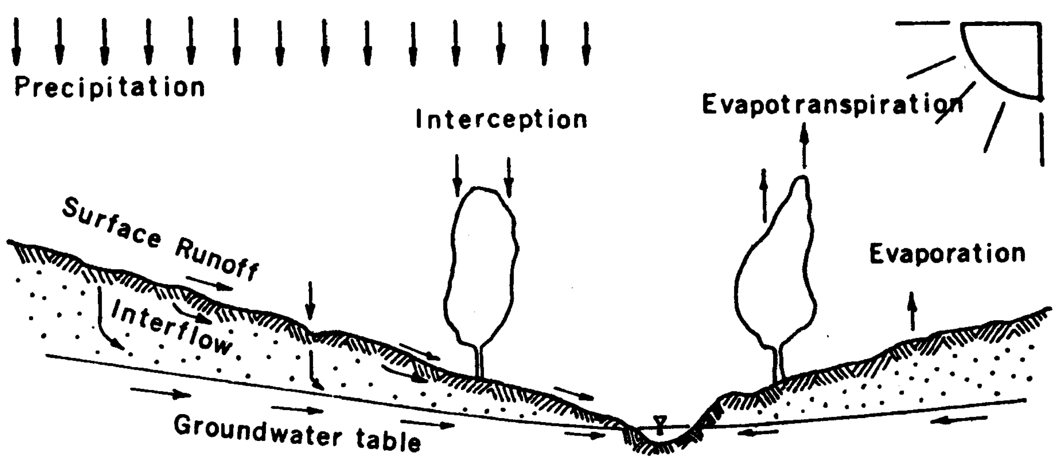
Several software programs were used to build, run, and analyze results from the HSPF model. The 'Better Assessment Science Integrating Point and Nonpoint Sources System' (BASINS) Version 3.0 interface (Kinerson et al., 2001) was used to generate model input data and to assist in the use of HSPF. 'An Interactive Windows Interface to HSPF' (WinHSPF) Version 2.0 interface (Duda et al., 2001) within BASINS was used for pre-processing the HSPF input file, known as the User Control Input (UCI) file. 'A Tool for The Generation and Analysis of Model Simulation Scenarios for Watersheds' (GenScn) Version 2.0 (Kittle et al., 2001), another interface within BASINS, was used for post-processing. 'A Tool for Managing Watershed Modeling Time-Series Data' (WDMUtil) Version 2.0 (Hummel et al., 2001) was used to prepare the input data files for HSPF, known as Watershed Data Management (WDM) files.

4.2 Model Setup

To better represent the spatial variation of fecal coliform sources in the Thumb Run watershed, the watershed was divided into five subwatersheds (Figure 3.1). The subwatersheds have varying characteristics, including size, slope, reach length, and landuse compositions.The subwatersheds were selected based on the availability of water quality data and uniformity of landuse. Subwatershed outlets were chosen to coincide with monitoring sites The subwatersheds were delineated using the automatic delineation tool provided in BASINS 3. The stream network was delineated based on USEPA's River Reach File 3 (RF3), and each subwatershed contains a single reach.

4.3 Hydrologic Modeling

Hydrology is the study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere (USEPA, 1999). Figure 4.1 depicts the hydrologic cycle.



Bicknell, et al, 2000

Figure 4.1. The hydrologic cycle.

Hydrologic modeling requires the following input data: climatic data, landuse, and stream geometry. With this input data, a hydrologic model can be calibrated to observed flow values. Model calibration involves adjusting hydrologic parameters that represent the watershed until the model reasonably replicates observed data. Once the model is calibrated, it should be validated for a time period other than the calibration period.

The HSPF watershed model was selected to simulate hydrology in the Thumb Run watershed. HSPF simulates runoff from four components: surface runoff from pervious areas directly connected to the channel network, surface runoff from impervious areas, interflow from pervious areas, and groundwater flow. This section focuses on the selection of parameters for the PWATER, IWATER, HYDR, and ADCALC sub-modules.

4.3.1 Procedure and Model Inputs

For hydrologic calibration, HSPF requires observed stream flow values. Stream flow values are not available for Thumb Run, therefore a reference watershed with USGS flow-monitoring data was selected to develop calibrated hydrologic parameters for Thumb Run. The hydrology in the Battle Run watershed was modeled in HSPF, then calibrated and validated with observed flow data from a USGS flow-monitoring station on Battle Run. The calibrated hydrologic parameters used to simulate hydrology in the Battle Run watershed were then applied to the Thumb Run HSPF model to simulate hydrology in the Thumb Run watershed.

The Battle Run watershed was chosen as a reference watershed because of its proximity to the Thumb Run watershed, similar hydrologic characteristics, and available USGS mean daily flow data (1958-present). A summary of the physical properties of the paired watersheds is presented in Table 4.1.

Table 4.1. Summary of the physical properties of the Thumb Run and Battle Run watersheds.

Physical Property	Thumb Run Watershed	Battle Run Watershed
Size (mi^2)	34	26
Slope (ft/ft)	0.0073	0.0084
Length of Reach (mi)	23.24	9.18
Prominent Soil Hydrologic Group	B	B
Landuse (%):		
Forest	49	46
Pasture/Cropland	51	53
Urban/Residential	1	1

The USGS station at Battle Run near Laurel Mills, VA (USGS Station 01662800) is approximately six miles from the Thumb Run confluence with the Rappahannock River. The location of the USGS Station 01662800 and the Battle Run watershed in relation to the Thumb Run Watershed is shown in Figure 4.2.

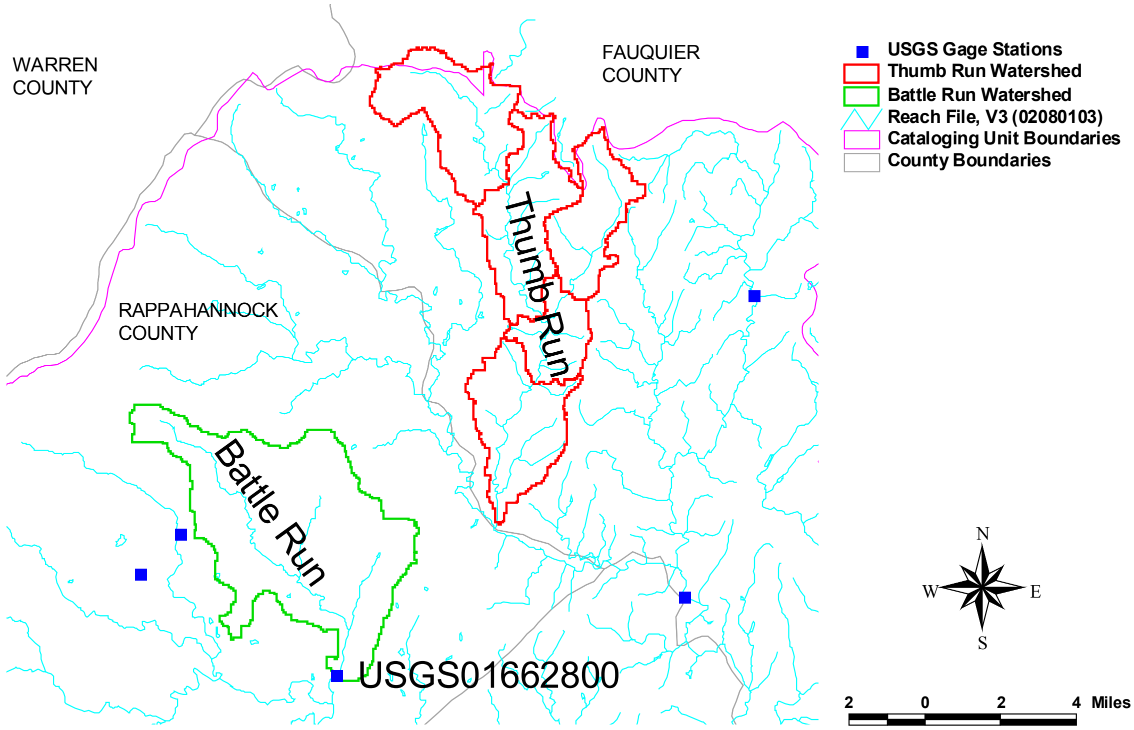


Figure 4.2. Location of reference watershed relative to the Thumb Run watershed.

HSPF requires that climatic data be entered into a properly formatted WDM file. USEPA has produced WDMs for all states in the U.S.A. Each WDM includes climatic data for major National Climate Data Center (NCDC) cooperative weather stations in the state. The WDMs were created for use with BASINS, and they are available to download off of the BASINS website. A description of how USEPA created these WDMs is provided in Appendix A.

The Virginia WDM created by USEPA includes climatic data for the Piedmont Research Station (Coop ID # 446712) from January 1, 1970 to December 31, 1995. This weather station near Orange, VA, was used for model simulation.

Precipitation data from weather stations that are closer to the Battle Run watershed, including smaller stations not included in USEPA's Virginia WDM, were also considered for model input. Figure 4.3 shows the locations of several Virginia weather stations that were considered as sources of climatic data input for the Battle Run hydrologic model. Table 4.2 lists weather stations near the Battle Run watershed and their historical period of record.

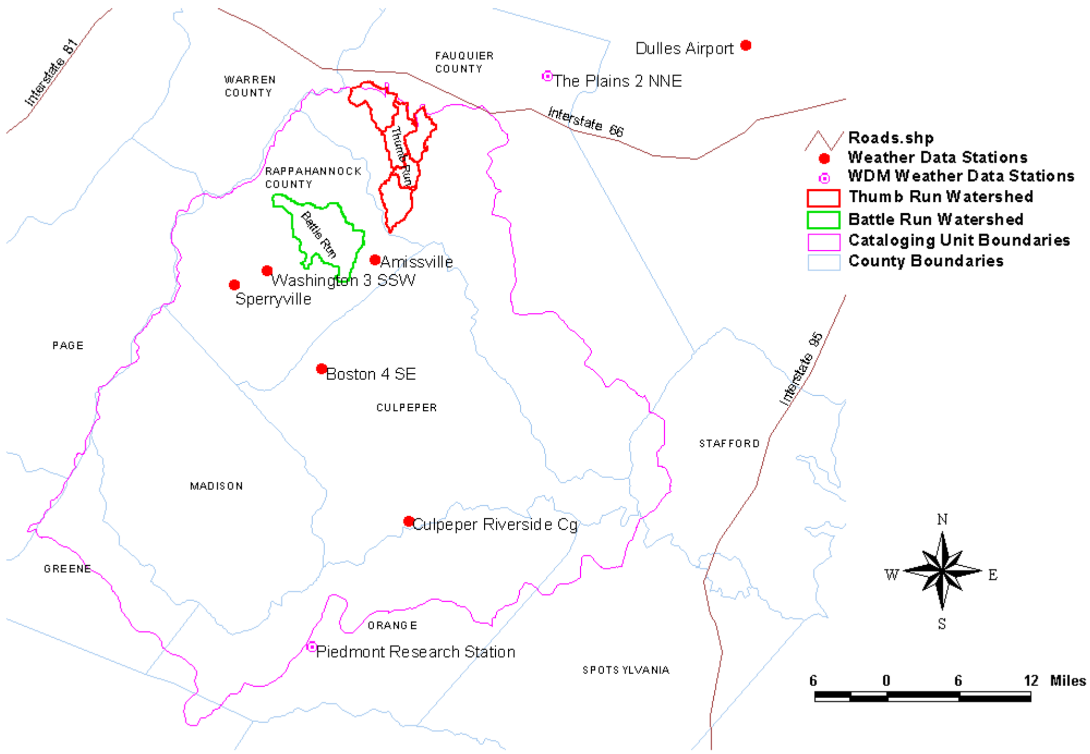


Figure 4.3. Locations of selected Virginia weather stations.

Table 4.2. Weather stations near the Battle Run watershed.

Weather Station	NCDC Coop ID #	Historical Period of Record
Amissville	440193	Aug 1, 1948 - Oct 19, 1983
Boston 4 SE	440860	Mar 12, 1997 - Present
Culpeper Riverside Cg	442159	Jul 1, 1979 - Present
Dulles Airport	448903	Jul 1, 1996 - Present
Piedmont Research Station	446712	Aug 1, 1948 - Present
The Plains 2 NNE	448396	Apr 1, 1954 - Present
Sperryville	447985	Apr 1, 1995 - Present
Washington 3 SSW	448902	Apr 1, 1979 – Feb 15, 1995 (missing 1981 – 1993)

The following weather stations were close to Battle Run, but do not have a sufficient record of precipitation data for the calibration and validation time periods: Amissville, Sperryville, Washington 3 SSE, and Boston 4 SE. The Plains 2 NNE and Culpeper Riverside Cg stations have a sufficient record of precipitation data for the desired time periods, but the storm periods are not consistent with Battle Run's observed peak flows. Data from the Piedmont station simulated flow values during storm events closest to observed values, and thus was the only climatic data used to model the Battle Run watershed hydrology.

4.3.2 Calibration

The calibration period selected from the Battle Run data was March 1, 1981, to June 15, 1985. This time period includes a range of hydrologic conditions. The observed flow data exhibits both low and high flow periods.

The HSPEXP software (Lumb et al., 1994), an expert system for calibration of HSPF, was used to develop a calibrated hydrologic model for the Battle Run watershed. HSPEXP calculates statistics for calibration criteria based on total and seasonal flow values and storm volumes. Suggestions for selecting storm durations are given in the "BASINS Technical Note 5, Using HSPEXP with BASINS/NPSM," (USEPA, 1999). This document suggests starting a storm period on the first day of significant precipitation and extending the period through the time when the flow returns to pre-storm levels. Using this guidance, a storm event baseline of 100 cfs was selected to define a storm period from the Battle Run flow data. With this baseline, twenty-two storm periods were available to perform statistical analysis on simulated flow results during the calibration period.

HSPEXP advises the user to adjust various hydrologic parameters until error statistics for such criteria as total annual runoff, storm volume, and seasonal variability are within specified limits. The hydrologic calibration parameters are listed in Appendix C. Many default values supplied by HSPF or mid-range values suggested in "BASINS Technical Note 6, Estimating Hydrology and Hydraulic Parameters for HSPF," were used in the calibrated model (USEPA, 2000). The parameters that were adjusted during calibration are:

- the lower zone nominal soil moisture storage (LZSN),
- the soil infiltration rate (INFILT),
- the groundwater recession rate (AGWRC).
- the fraction of infiltrating water that is lost to deep aquifers (DEEPFR),
- the evapotranspiration by riparian vegetation (BASETP),
- the amount of interception storage (CEPSC),

- the nominal upper zone soil moisture storage (UZSN),
- the amount of water which enters the ground from surface detention storage and becomes interflow (INTFW),
- the extent of interflow recession (IRC),
- the amount of evapotranspiration from the lower zone (LZETP).

The selected values for the calibrated parameters were all within acceptable ranges defined in the "BASINS Technical Note 6."

The calibration criteria for the Battle Run hydrologic model are shown in Table 4.3. Daily flow results for the calibration time period are plotted in Figure 4.4. A scatter plot of simulated flow versus observed flow for the calibration time period is shown in Figure 4.5 and flow duration curve is shown in Figure 4.6.

Table 4.3. Hydrology calibration and model performance for the period of 3/1/81 through 6/15/85.

Criterion	Simulated	Observed	% Error	% Error Criteria
Total annual runoff (in)	61.39	58.82	4.4	10
Total of highest 10% flows (in)	29.33	27.93	5	15
Total lowest 50% flows (in)	20.88	22.844	-8.8	10
Total storm volume (in)	258.02	298.261	-13.5	15
Baseflow recession rate	0.95	0.94	-0.01	0.01
Summer flow volume (in)	9.28	8.16	13.7	-
Winter flow volumes (in)	18.77	17.97	4.5	-
Summer storm volume (in)	2.38	2.46	-3.3	15

The error criteria were established to ensure that the model properly simulates both critical conditions of low flow periods and storm events. The simulated results for the calibration time period match well with the observed data under both critical conditions.

4.3.3 Validation

Validation of a model is the "process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation" (USEPA, 2001). The Battle Run calibrated hydrologic model was validated by running the model for a time period different from the calibration time period and reviewing error statistics.

The model was validated for the time period of January 1, 1990 to June 30, 1993. This period also includes critical flow conditions. Twenty-six storm periods were defined for the validation period.

Daily flow results for the validation time period are plotted in Figure 4.7. A scatter plot of simulated flow versus observed flow for the validation time period is shown in Figure 4.8 and a flow duration curve is shown in Figure 4.9. Validation criteria are given in Table 4.4.

Table 4.4. Validation and model performance for the period of 1/1/90 through 6/30/93.

Criterion	Simulated	Observed	% Error	% Error Criteria
Total annual runoff (in)	53.54	58.11	-7.9	10
Total of highest 10% flows (in)	25.33	24.41	3.8	15
Total lowest 50% flows (in)	6.38	8.80	-27.5	10
Total storm volume (in)	19.24	22.51	-10.1	15
Baseflow recession rate	0.95	0.94	-0.01	0.01
Summer flow volume (in)	5.92	5.78	2.4	-
Winter flow volumes (in)	17.92	17.37	3.2	-
Summer storm volume (in)	0.58	0.56	3.6	15

The validation results indicate that the calibrated model simulates the hydrology of the Battle Run watershed well. The one exception is the total of the lowest 50 percent of flows simulated during the validation period, which is significantly lower than the observed value. This is a result of under simulating flow during the summer of 1992. The discrepancy between observed flow data and simulated results during this period, as well as other minor discrepancies during other periods, are likely due to differences between the rainfall record at the Piedmont rain gage station and the Battle Run watershed. The Piedmont station is approximately thirty miles south of the Battle Run stream gage, therefore the station is not expected to record the same rainfall that would be observed within the Battle Run watershed. As discussed earlier though, this rainfall data is the best available for the Battle Run hydrologic model.

4.3.4 Hydrologic Modeling Conclusions

The Battle Run hydrologic model simulates the hydrology of Battle Run well. The model partitions the total annual flow into approximately eight percent surface runoff (SURO), twenty-nine percent interflow (IFWO), and sixty-three percent active groundwater (AGWO).

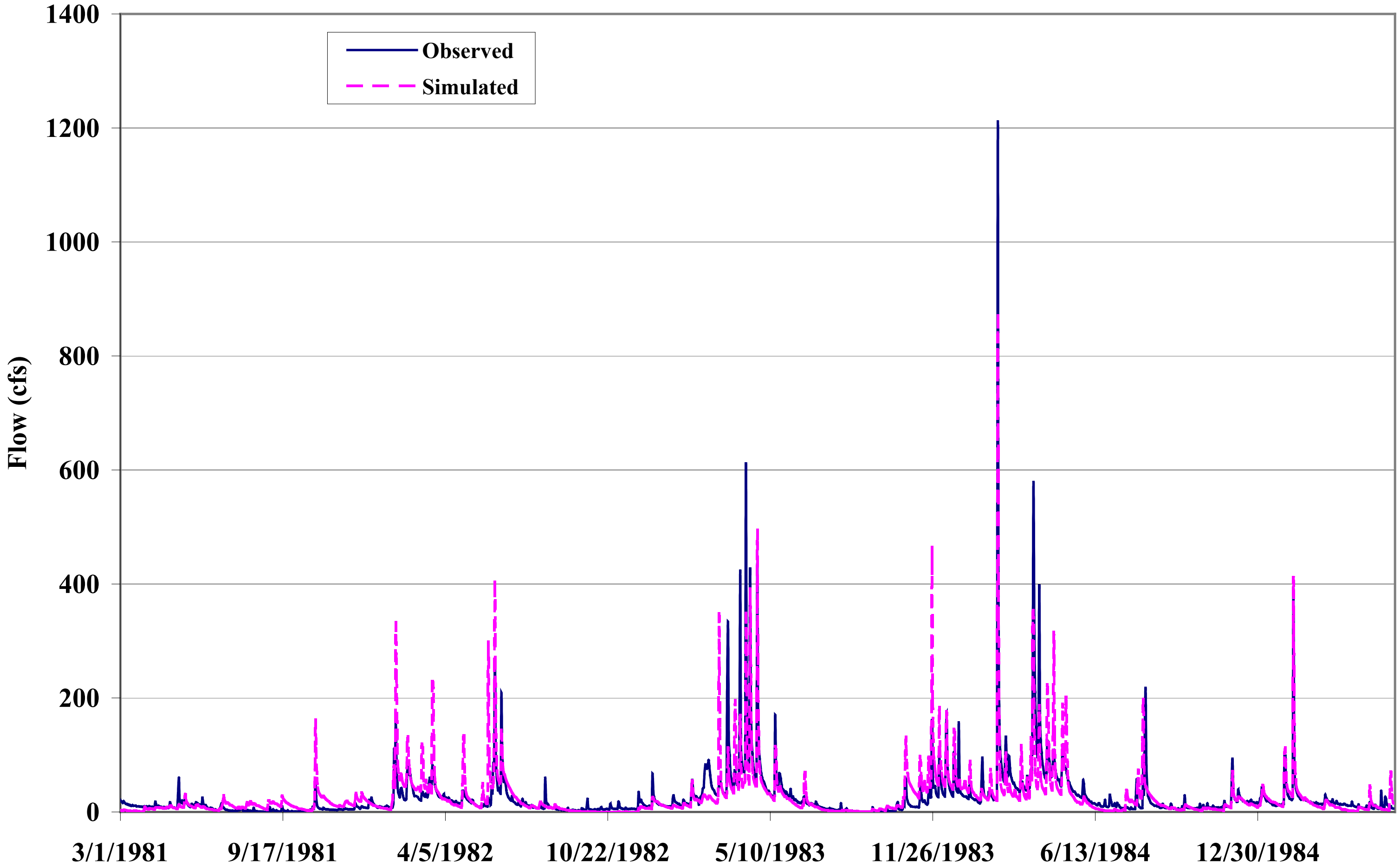


Figure 4.4. Simulated and observed daily stream flow for calibration time period (3/1/1981 – 6/15/1985).

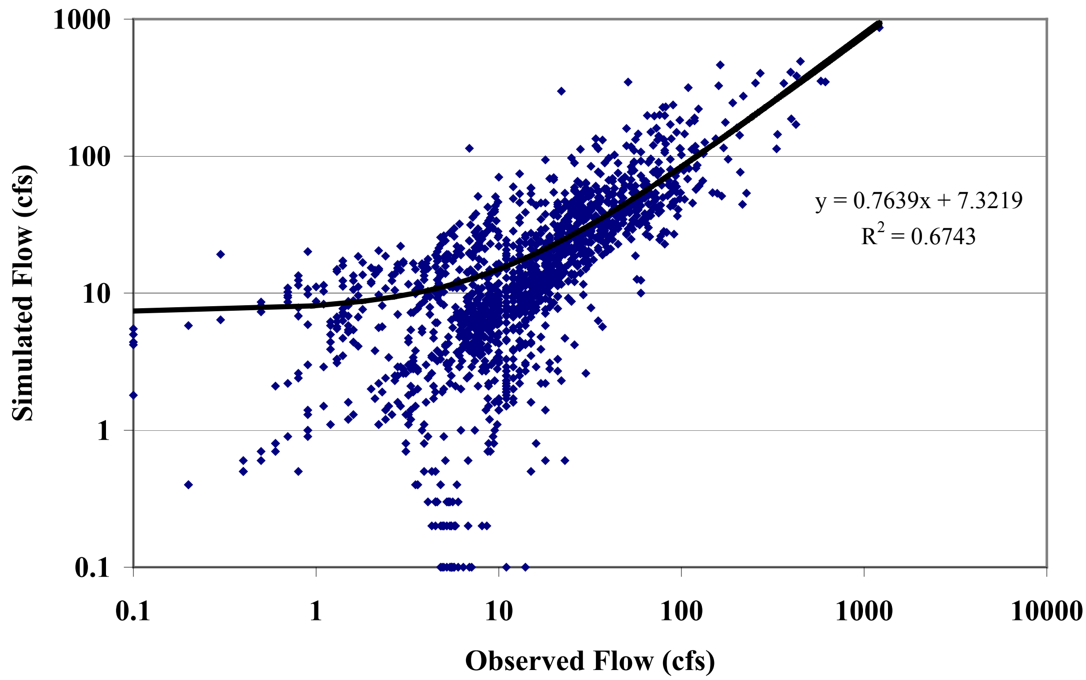


Figure 4.5. Simulated versus observed daily stream flow for calibration time period (3/1/1981 – 6/15/1985).

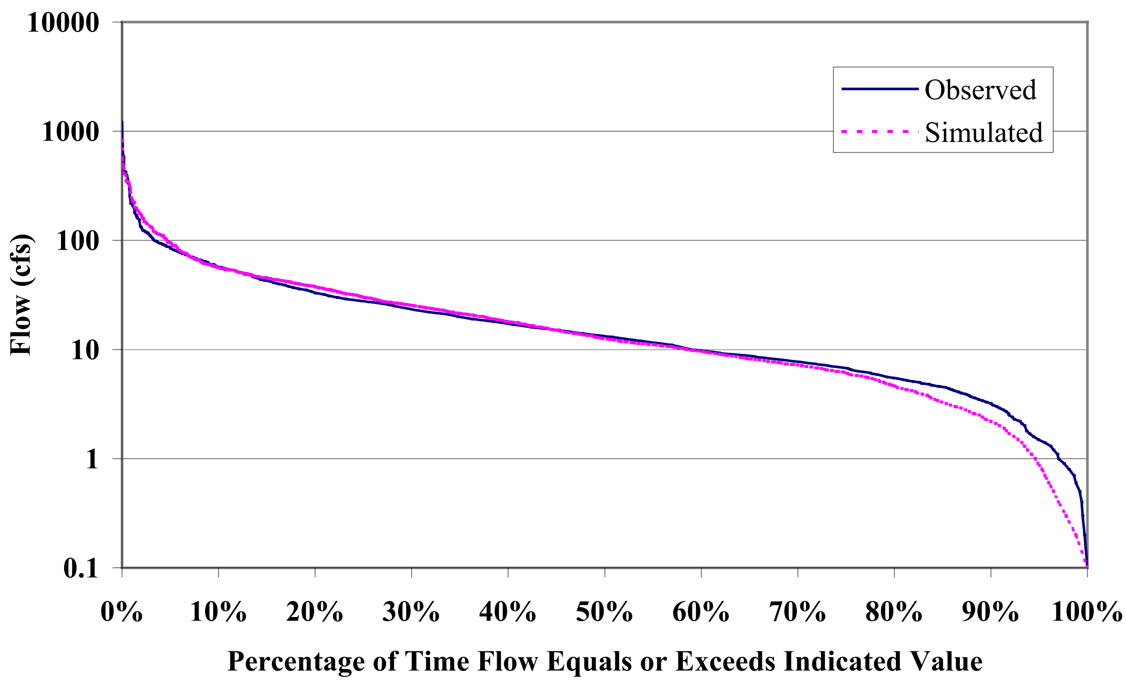


Figure 4.6 Battle Run flow duration curve for calibration time period.

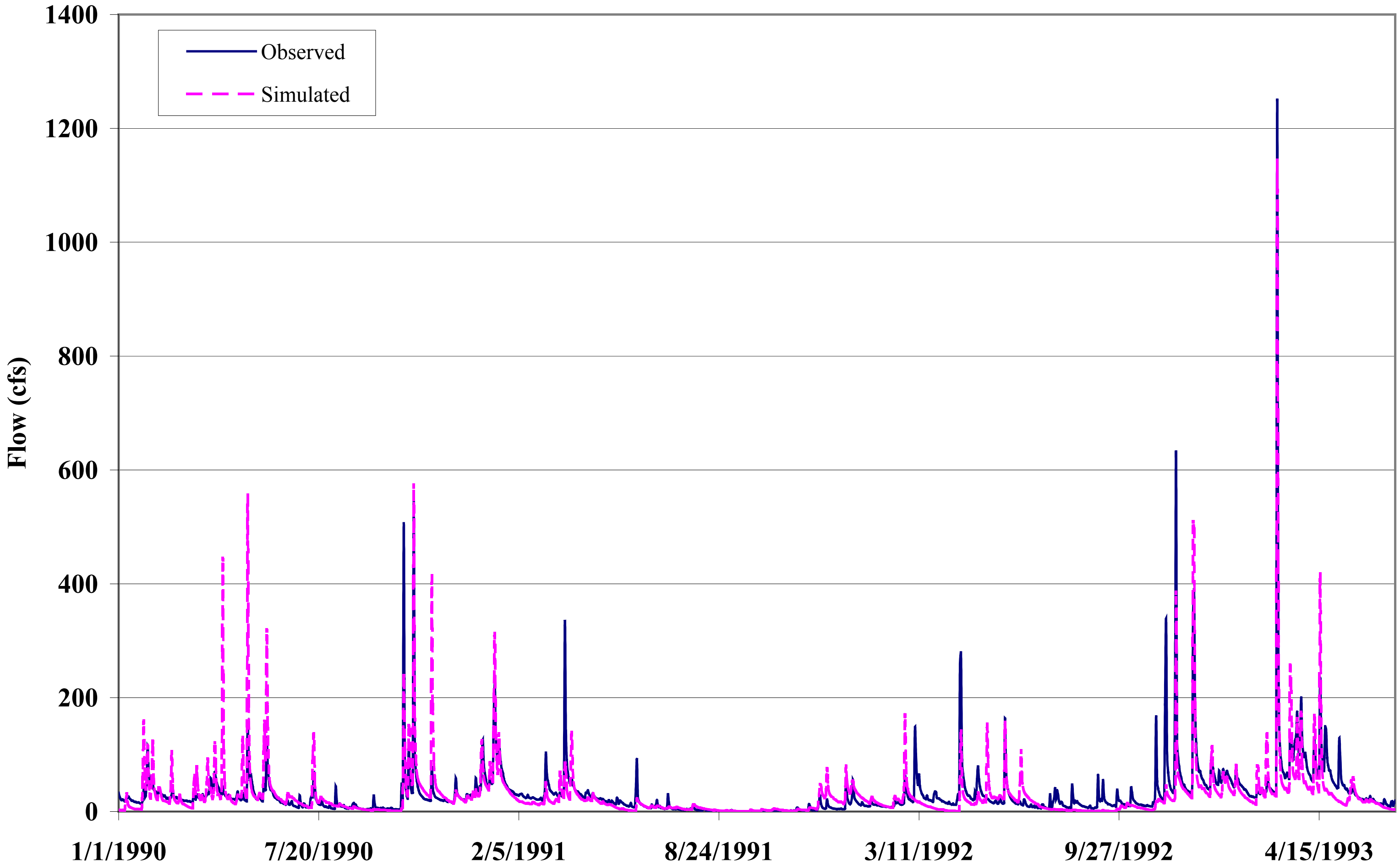


Figure 4.7. Simulated and observed daily stream flow for validation time period (1/1/1990 – 6/30/1993).

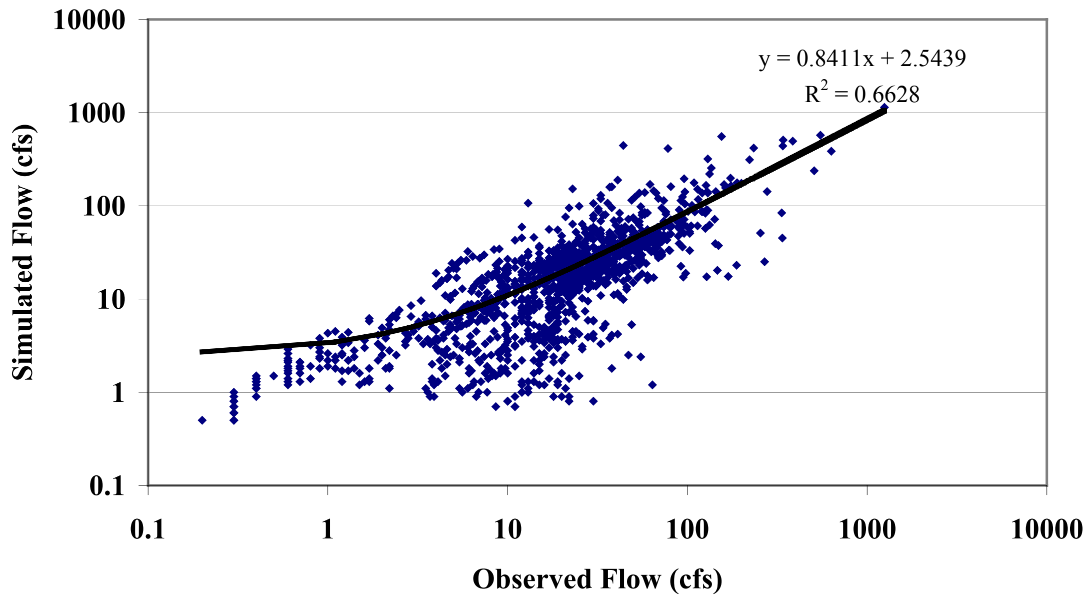


Figure 4.8. Simulated versus observed daily stream flow for validation time period (1/1/1990 – 6/30/1993).

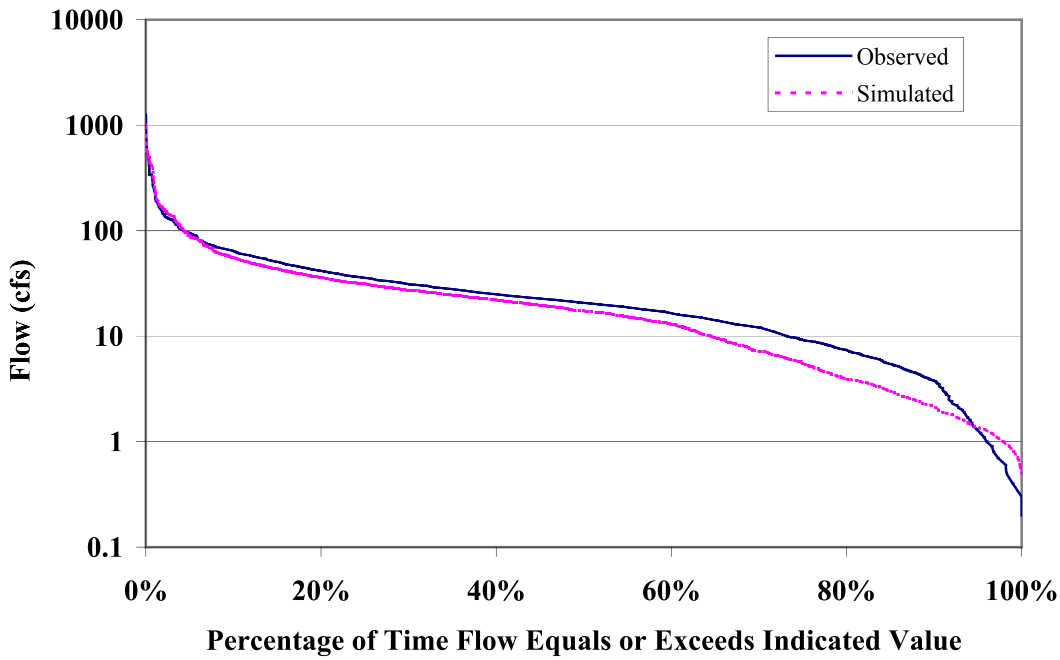


Figure 4.9 Battle Run flow duration curve for validation time period

The hydrologic model was run for the water quality calibration period (October 1, 1996 through September 30, 2001) with the new WDM created for that time period. This analysis was performed to assess the paired-watershed approach used for the hydrologic calibration. The model simulated observed flows well during this time period and all error statistics except for the total storm volume were within acceptable criteria. The undersimulation of total storm volume can be explained by the fact that several storms within the Battle Run watershed during this time period were not recorded at the Dulles weather station which was used for precipitation input in the new WDM.

The Battle Run hydrologic model was calibrated and validated using meteorological data from the Piedmont Research Station because this data was found to have the best relationship to the Battle Run flow. The new WDM created for the Thumb Run water quality calibration was created from Dulles Airport meteorological data because it was the most complete dataset for this time period and closer to the Thumb Run watershed than the Piedmont station. The Battle Run hydrology parameters were simply applied to the Thumb Run watershed with the new WDM for water quality calibration. The calibrated PERLND, IMPLND, and RCHRES parameters were input into the Thumb Run watershed model, and were only adjusted to account for different slopes and reach lengths.

4.4 Water Quality Modeling

Water quality modeling requires various input data including the following: climatic data, landuse, stream flow, and estimated source loadings. With this input data, a water quality model can be calibrated to observed pollutant concentrations.

The HSPF model simulates the fate and transport of fecal coliform in the Thumb Run watershed. This section focuses on the selection of parameters for the PQUAL, IQUAL, and GQUAL sub-modules.

The time period selected for water quality calibration was October 1, 1996 to September 30, 2001. This time period was selected to coincide with the time period of available monitoring data collected by both VADEQ and RRRC. The time period was also limited by the available meteorological data from the Dulles Airport weather station. The starting date was selected to avoid modeling hurricane conditions recorded in September of 1996.

4.4.1 Procedure and Model Inputs

Many data inputs were needed to create the water quality model. The following sections describe now these inputs were developed and used.

4.4.1.1 Landuse

The subwatersheds used in the water quality model have varying landuse compositions (Table 2.1). Table 4.5 shows the landuse distribution for each subwatershed. The landuse types within each subwatershed are represented in the model as individual pervious (PERLND) and impervious (IMPLND) land segments, totaling 30 PERLNDs and 11 IMPLNDS.

Table 4.5. Spatial distribution of landuse types in the Thumb Run watershed.

Thumb Run Subwatershed	TMDL Landuse Category (acres)							Total (acres)
	Crop-land	Farm-stead	Forest	Pasture 1	Pasture 2	Rural Residential	Urban	
West1	51.7	14.7	3423.7	1973.1	207.5	5.3	0.0	5676.0
West2	27.5	17.0	1902.0	2938.8	204.0	11.4	0.4	5101.1
East1	171.5	11.9	1384.9	2003.6	121.3	7.0	0.0	3700.2
Main1	0.0	9.3	1349.2	1000.4	39.9	4.8	0.0	2403.6
Main2	174.8	21.9	2557.9	1960.2	151.5	25.7	2.7	4894.7
Total	425.4	74.8	10617.6	9876.2	724.2	54.2	3.1	21775.6

4.4.1.2 Climatic Data

The desired water quality calibration time period is outside of the time period for which USEPA has created weather WDMs, so a new WDM file was created to input meteorological data into the model. Data from the Dulles Airport weather station (Co-op ID # 448903), approximately 30 miles east of the Thumb Run wastershed, was used as input because it was the most complete dataset for the desired time period. The precipitation data from Dulles Airport was supplemented with rainfall data recorded by several volunteers residing within the watershed. If rainfall was recorded on a given date by the volunteers, but not recorded by the weather station on that date or within a day of that date, the rainfall measurement recorded by the volunteers was added to the Dulles precipitation dataset. A description of the preparation of the climatic WDM file created for the water quality calibration is found in Appendix B.

4.4.1.3 Active Best Management Practices

There were eighteen active best management practices (BMPs) in the watershed during the water quality calibration time period (Huber, 2001). BMPs are considered “active” when they are within their life expectancy. Figure 4.10 displays the location of these BMPs in the watershed.

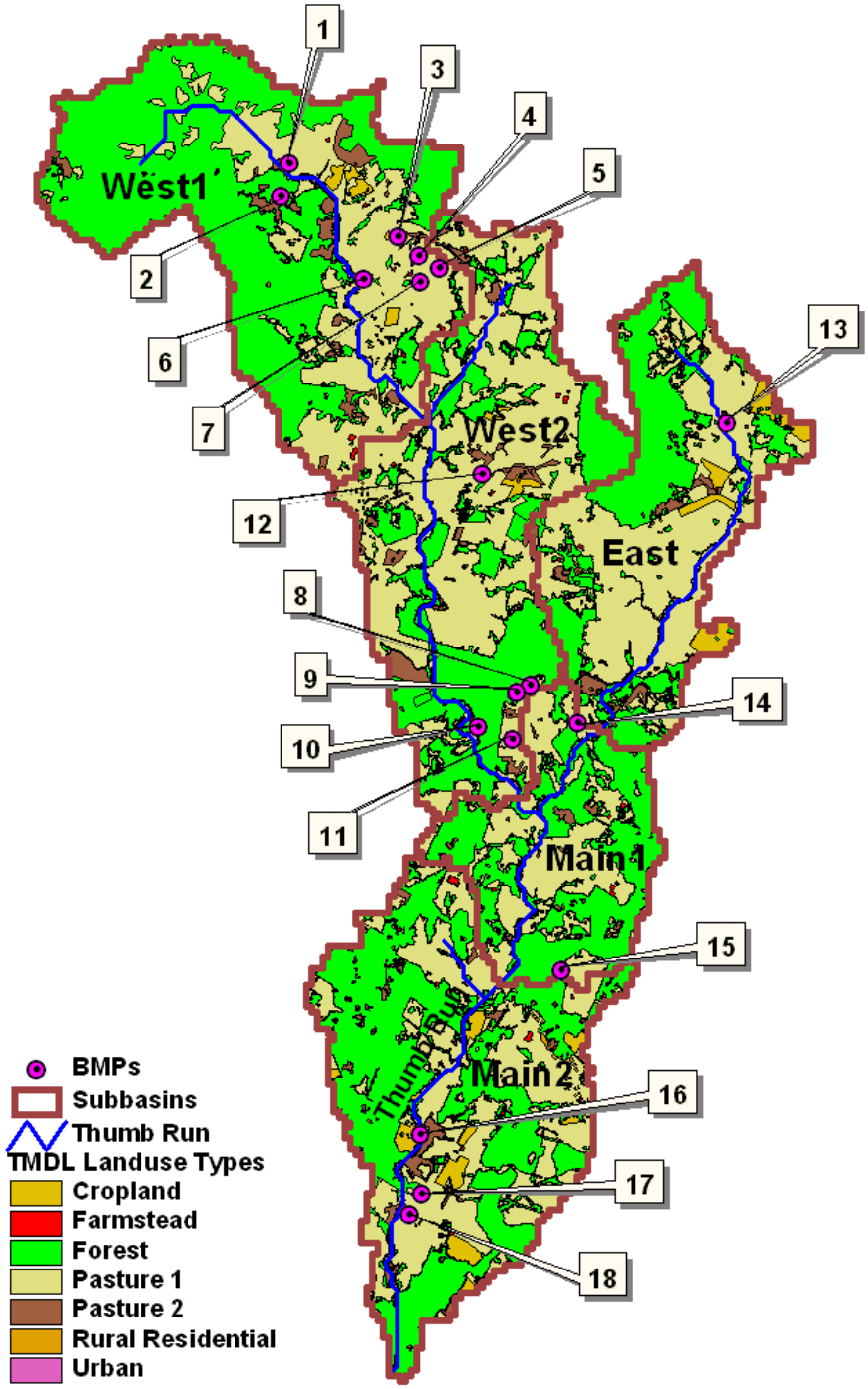


Figure 4.10. Active BMPs in the Thumb Run watershed.

BMPs were modeled using the BMPRAC module. This module applies removal fractions to the loadings from PERLANDs and IMPANDs based on the removal efficiency of the BMP type. The types of BMPs in the watershed and their removal efficiencies are given in Table 4.6.

Table 4.6. Types of BMPs found in the Thumb Run watershed and their removal efficiencies.

Type of BMP	VADCR Practice Code	Removal Efficiency	Source
Stream Protection	WP-2	100%	Estimated
Permanent Vegetative Cover	SL-1	-	CH2M HILL, 2001
Grazing Land Protection	SL-6	51%	CH2M HILL, 2001
Woodland Erosion Stabilization	FR-4	59%[1]	CH2M HILL, 2001

1 Woodland erosion stabilization is assumed to have the same removal efficiency as permanent vegetative cover on critical areas (Lunsford, 2001b).

The acres of land and type of landuse that benefits from each individual BMPs are listed in Table 7. A total of 477 acres within the watershed are benefited by BMPs. Four-point-two percent of all pasture1 landuse and 8.7 percent of all cropland landuse is benefited by BMPs.

Table 4.7. Characteristics of BMPs in the Thumb Run watershed.

BMP #	DCR Code	Subwatershed Where BMP is Located	Acres Benefited by BMP	Landuse Benefited by BMP
1	WP-2	West1	35.9	Pasture 1
2	SL-1	West1	7	Forest
3	SL-1	West1	36	Pasture 1
4	SL-6	West1	20.1	Pasture 1
5	SL-6	West1	35.8	Pasture 1
6	WP-2	West1	38.3	Pasture 1
7	SL-6	West1	6	Pasture 1
8	SL-6	West2	41	Pasture 1
9	SL-6	West2	35.4	50% Pasture 1 50% Forest
10	FR-4	West2	0	-
11	WP-2	West2	58.2	Pasture 1
12	SL-6	West2	13.6	Pasture 1
13	SL-6	East	6.8	Pasture 1
14	SL-6	East	14	Pasture 1
15	SL-6	Main1	24.3	Pasture 1
16	SL-6	Main2	36.9	Cropland
17	SL-6	Main2	34.4	Pasture 1
18	SL-6	Main2	33.1	Pasture 1

4.4.1.4 Pollutant Source Representation

There are both point and nonpoint sources of fecal coliform accounted for in the model of the Thumb Run watershed. In general, point sources are modeled as constant fecal loads to the reach. Fecal coliform deposited on the land surface was considered to be a nonpoint source and modeled as an accumulation of fecal coliform on the land, washed off into the stream during storm events. The amount of accumulation and transport characteristics varied by subwatershed, landuse, and season. Fecal coliform deposited directly in the stream from nonpoint sources was modeled as a direct source, varying monthly. Two key considerations in calibrating the water quality model were the amount of fecal coliform that will wash-off from the land surface during a storm event and the extent of die-off of fecal coliform both on the land surface and in the stream.

The amount of surface runoff that will remove 90 percent of the land applied fecal coliform per hour (WSQOP), affects the peak concentration of fecal coliform in the stream. Reducing the value of this parameter increases the peak concentrations, thus the value can be adjusted until simulated peaks match observed peaks.

Fecal coliform die-off on the land surface and in-stream was modeled with a first order equation of the form:

$$C_t = C_0 10^{-Kt} \qquad [4.1]$$

where:

C_t = the concentration or load at time t (cfu or cfu/100 mL),
C_0 = the initial concentration or load (cfu or cfu/100 mL),
K = decay rate (1/day), and
t = time (day).

The decay rate for fecal coliform deposited on the land surface was specified implicitly by setting the maximum accumulation of fecal coliform on each land segment (SQOLIM) to be a factor of the daily accumulation rate (ACQOP). The in-stream decay rate (FSTDEC) was entered explicitly using the general decay module in HSPF. These parameters accounting for die-off were adjusted until simulated concentrations were similar to observed concentrations.

4.4.1.4.1 Direct Loads

There was only one regulated point source of fecal coliform in the Thumb Run watershed, the Camp Moss Hollow Waste Water Treatment Plant (WWTP). The WWTP is currently inactive, but was modeled as a point source to the West1 reach for the entire water quality calibration time period. A constant load of 7.57×10^9 cfu/day was calculated for the WWTP by multiplying the design flow by a concentration of 200 cfu/100mL (Section 3.1). No waste load allocation was developed for this source because it is already offline.

Nonpoint sources of fecal coliform that were modeled as direct sources include: direct defecation in the stream from livestock and wildlife, biosolids application, and the direct load from one failing septic system. The direct load from the failing septic system was modeled as a straight pipe, with a constant load of 5.36×10^9 cfu/day to the West1 reach.

Biosolids were only applied over a three-day period (June 18-20, 2001) during the water quality calibration period (Section 3.2.5). Because there was such a small amount of biosolids application during this period, the fecal coliform contribution from the biosolids application was modeled as a direct source to the East reach on the date of the first significant storm after the application (June 23, 2001). This methodology assumes that the fecal coliform in the biosolids did not reach the stream until storm runoff washed it off. Die-off while the biosolids sat on top of the land surface was accounted for by using Equation 4.1 with an estimated K of 0.3.(value for stored poultry litter on the soil surface from Crane et al., 1980). This methodology also assumes that only 80 percent of the fecal coliforms existing at the time of wash off actually reached the stream (USEPA, 2001). The geometric mean fecal coliform density in biosolids from the Blue Plains Waste Water Treatment Plant for the month biosolids were applied (1,246 cfu/g), and the recorded mass applied each day were used to estimate the loading from the biosolids application.

Using the methodology described in Section 3.2.1 and 3.2.3, the daily fecal coliform loading from livestock and wildlife defecating directly in the stream was estimated for each month. Table 4.8 shows the daily direct fecal coliform loads to the reaches in each subwatershed from nonpoint sources, with the exception of the biosolids application in the East subwatershed, which was only added on one day.

Table 4.8. Monthly direct nonpoint fecal coliform loads to Thumb Run for each subwatershed.

Month.	Monthly fecal coliform loads by subwatershed (x 10^9 cfu/month)											Total (x 10^9 cfu/month)			
	West1			West2		East		Main1		Main2					
	Live stock	Wild life	Septic	Live stock	Wild life	Live stock	Wild life	Live stock	Wild life	Live stock	Wild life	Live stock	Wild life	Septic	Total
Jan.	1,688	7	166	2,251	6	2,532	4	1,182	3	1,984	6	9,636	26	166	9,828
Feb.	1,525	6	150	2,033	6	2,287	4	1,067	3	1,792	5	8,704	23	150	8,877
Mar.	2,532	7	166	3,376	6	3,798	4	1,772	3	2,976	6	14,454	26	166	14,646
Apr.	3,267	7	161	4,356	6	4,900	4	2,287	3	3,840	5	18,651	25	161	18,837
May	3,376	7	166	4,501	6	5,064	4	2,363	3	3,968	6	19,272	26	166	19,465
Jun.	4,084	7	161	5,445	6	6,125	4	2,859	3	4,800	5	23,313	25	161	23,499
Jul.	4,220	7	166	5,626	6	6,330	4	2,954	3	4,960	6	24,091	26	166	24,283
Aug.	4,220	7	166	5,626	6	6,330	4	2,954	3	4,960	6	24,091	26	166	24,283
Sep.	3,267	7	161	4,356	6	4,900	4	2,287	3	3,840	5	18,651	25	161	18,837
Oct.	2,532	7	166	3,376	6	3,798	4	1,772	3	2,976	6	14,454	26	166	14,646
Nov.	2,450	7	161	3,267	6	3,675	4	1,715	3	2,880	5	13,988	25	161	14,174
Dec.	1,688	7	166	2,251	6	2,532	4	1,182	3	1,984	6	9,636	26	166	9,828
Total	34,850	80	1,956	46,464	74	52,271	52	24,396	33	40,961	66	198,941	305	1,956	201,203

4.4.1.4.2 Land-based Loads

Fecal coliform loads deposited on the land surface were modeled as nonpoint sources, requiring a storm event to be transported to the stream. Sources contributing land loads are livestock, wildlife, pets, and failing septic tanks. The monthly fecal coliform loading by landuse for all modeled nonpoint sources in the watershed is shown in Table 4.9. The total population of each source within the landuse was multiplied by the fecal coliform production (cfu/day) for that source (Table 3.9). Daily fecal coliform loadings to an acre of landuse (cfu/acre-day) in each subwatershed are presented in Appendix F. These monthly values were input to the HSPF model in the MON-ACCUM module.

Table 4.9. Monthly nonpoint fecal coliform loadings to landuse types within the Thumb Run watershed.

Month	Fecal Coliform Loadings (x 10^9 cfu/month)							
	Cropland	**Pasture 1**	**Pasture 2**	**Farmstead**	**Rural Res**	**Urban**	**Forest**	**Total**
January	39	1,038,259	147,741	4,200	2,923	0	1,005	1,194,167
February	35	937,783	133,443	3,793	2,640	0	908	1,078,602
March	39	1,034,038	147,144	4,200	2,923	0	1,005	1,189,349
April	38	996,597	141,819	4,064	2,828	0	972	1,146,320
May	39	1,029,817	146,547	4,200	2,923	0	1,005	1,184,530
June	38	992,513	141,241	4,064	2,828	0	972	1,141,657
July	39	1,025,596	145,949	4,200	2,923	0	1,005	1,179,712
August	39	1,025,596	145,949	4,200	2,923	0	1,005	1,179,712
September	38	996,597	141,819	4,064	2,828	0	972	1,146,320
October	39	1,034,038	147,144	4,200	2,923	0	1,005	1,189,349
November	38	1,000,682	142,397	4,064	2,828	0	972	1,150,982
December	39	1,038,259	147,741	4,200	2,923	0	1,005	1,194,167
Total	460	12,149,778	1,728,934	49,450	34,413	0	11,832	13,974,867

Each landuse receives fecal coliform loadings from different sources and the quantity of that loading varies amongst subwatersheds. The nonpoint sources estimated to contribute fecal coliform loads to the landuse types are described below:

1. <u>Cropland</u>: The only recorded land application of waste within the watershed is the biosolids application, which is modeled as a point source. Suitable habitat for some wildlife species includes cropland. Wildlife defecating on cropland is the only modeled source of fecal coliform loads within the watershed.
2. <u>Pasture 1</u>: Livestock and wildlife defecate on pasture 1. The populations of each species on this landuse within each subwatershed was determined by the methodology described in Section 3.2.1 and 3.2.3.

3. Pasture 2: Pasture 2 receives fecal coliform loads from the same sources as pasture 1, but has a higher load per acre because it is stocked with twice the number of livestock as pasture 1.
4. Farmstead: Failing septic systems and pet waste contribute fecal coliform loads to the farmstead landuse.
5. Rural Residential: The rural residential landuse receives the same source loadings per acre as the farmstead landuse.
6. Urban: Fecal coliform loads from the watershed's urban landuse area (only commercial and transportation areas in this case) are not considered to be significant because the area is relatively small, consisting of only 3 acres compared to the total watershed area of 21, 776 acres.
7. Forest: Wildlife defecating on land is the only source of fecal coliform loads.

4.4.2 Calibration

After the model set-up and data input was complete, the model was calibrated to simulate fecal coliform concentration levels monitored at the sampling sites. VADEQ monitored fecal coliform concentrations at the outlets of the West1 and East subwatersheds eight times from June 1999 to May 2000. They monitored the outlet of the Main1 subwatershed fourteen times during the water quality calibration time period. RRRC monitored concentrations at the outlets of the West2, East, and Main1 subwatersheds 31 times during both low and high flow events from May 2000 to September 2001.

The following fecal coliform parameters were adjusted during calibration to achieve a better simulation:

- the wash-off rate that removes 90 percent of the constituent from the land surface (WSQOP),
- the rate of accumulation of the constituent on the land surface (ACQOP or MON-ACCUM),
- the maximum accumulation of the constituent on the land surface (SQOLIM or MON-SQOLIM),
- the constituent concentration in interflow (IOCQ),
- the constituent concentration in active groundwater (AOQC), and
- the first-order decay rate of the constituent (FSTDEC).

4.4.3 Results

Graphs comparing the simulated concentrations and the observed concentrations were used to visually assess the accuracy of the simulations. Figures 4.11 through 4.15 display these graphs for each subwatershed. The monitoring data was distinguished between that taken by VADEQ and that taken by RRRC because different sampling and laboratory techniques were used to derive these concentrations.

Initial values of ACQOP developed from estimated animal populations and literature values of fecal coliform production were used in final calibration of the model.

Adjusting WSQOP had a significant impact on the simulated peak fecal coliform concentrations. Reducing this value increased the contribution of fecal coliform from livestock and wildlife land loads. The value was set at 0.6 in/hr.

Changing SQOLIM also effected the contribution from these sources. The parameter was adjusted from two to nine times ACQOP, based on values used by experts (BASINS list serve) and values used in previously approved TMDLs. SQOLIM was set at nine times ACQOP, simulating a fecal coliform decay rate of 0.045 day^{-1} in waste deposited on the land surface.

A fecal coliform decay rate in the stream (FSTDEC) of 1.15 day^{-1} was used (USEPA, 1985).

Changing the fecal coliform concentration in interflow (IOQC) and active groundwater (AOQC) did not have a significant impact on the simulation results. Values for IOQC and AOQC were set at low levels, 1416 cfu/ft^3 (5 cfu/100 mL) and 283.2 cfu/ft^3 (1 cfu/100 mL) respectively, based on values set for previously approved TMDLs in the area.

The selected values for the HSPF water quality parameters are provided in Appendix C.

Some observed high concentrations were not simulated with the water quality model. This is likely a result of missed storms. Precipitation data from Dulles Airport was supplemented with volunteer data when available, but it is possible that several storms within the watershed were not included in the precipitation data set.

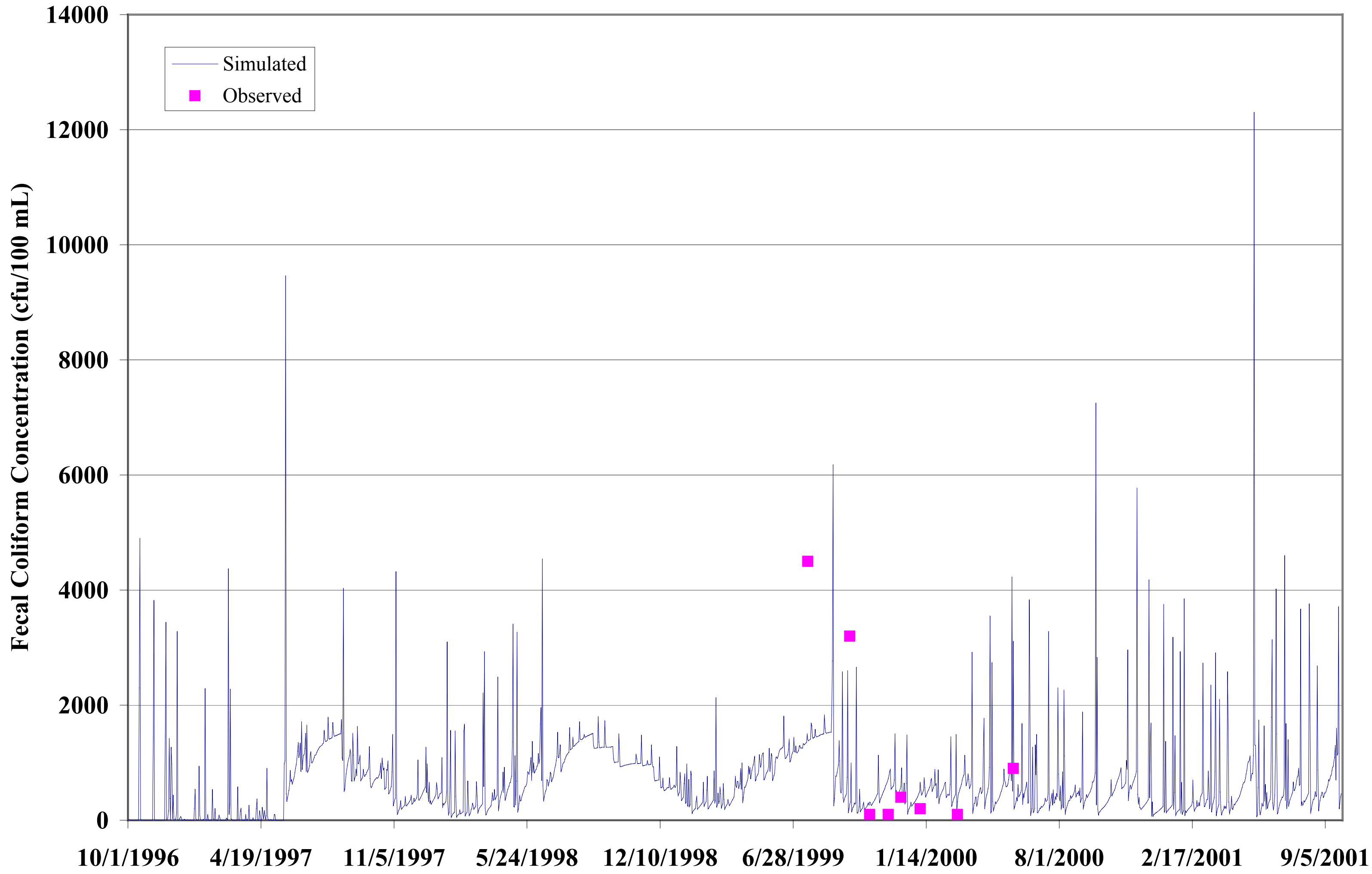


Figure 4.11. Fecal coliform calibration for West1 reach.

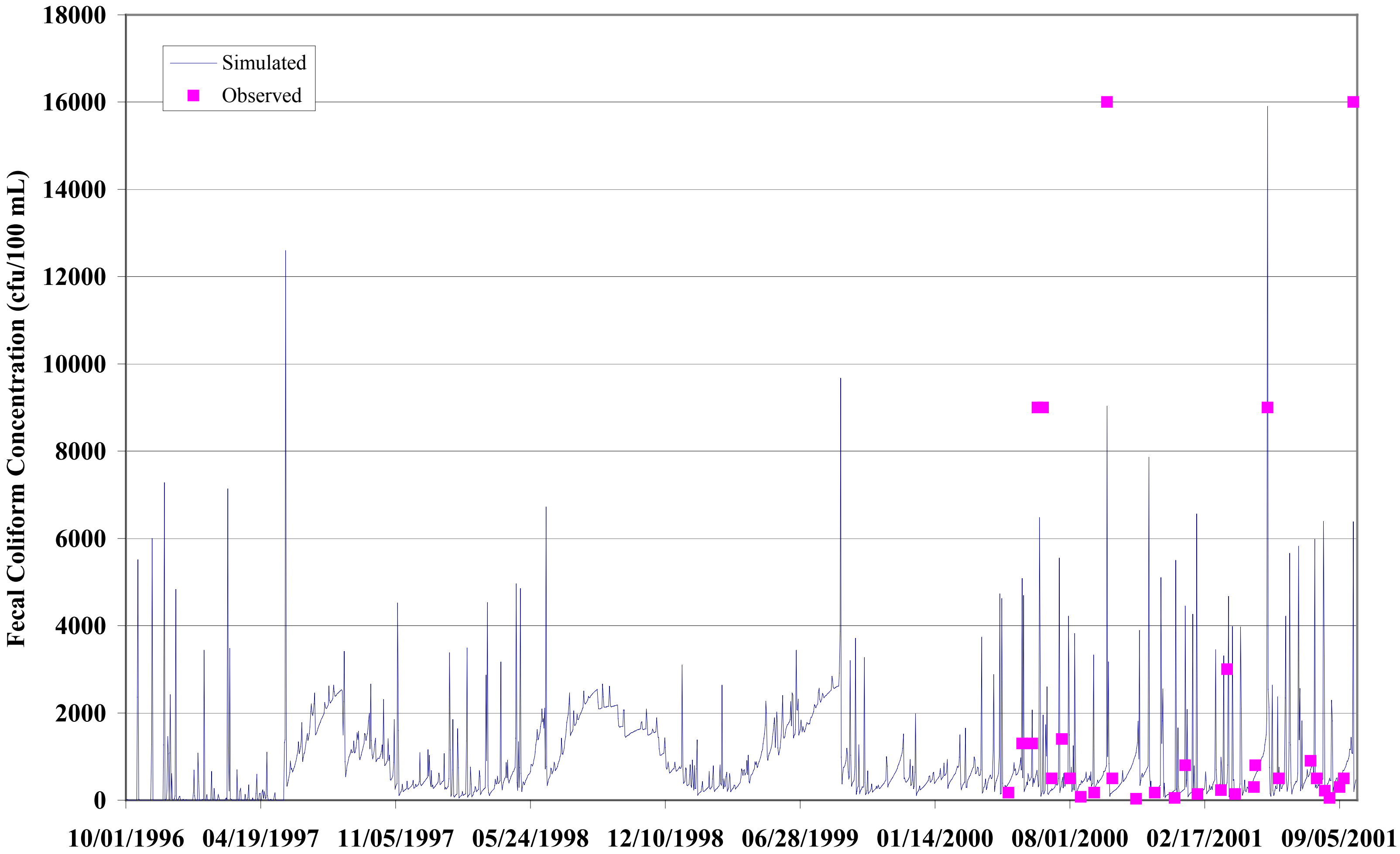


Figure 4.12. Fecal coliform calibration for West2 reach.

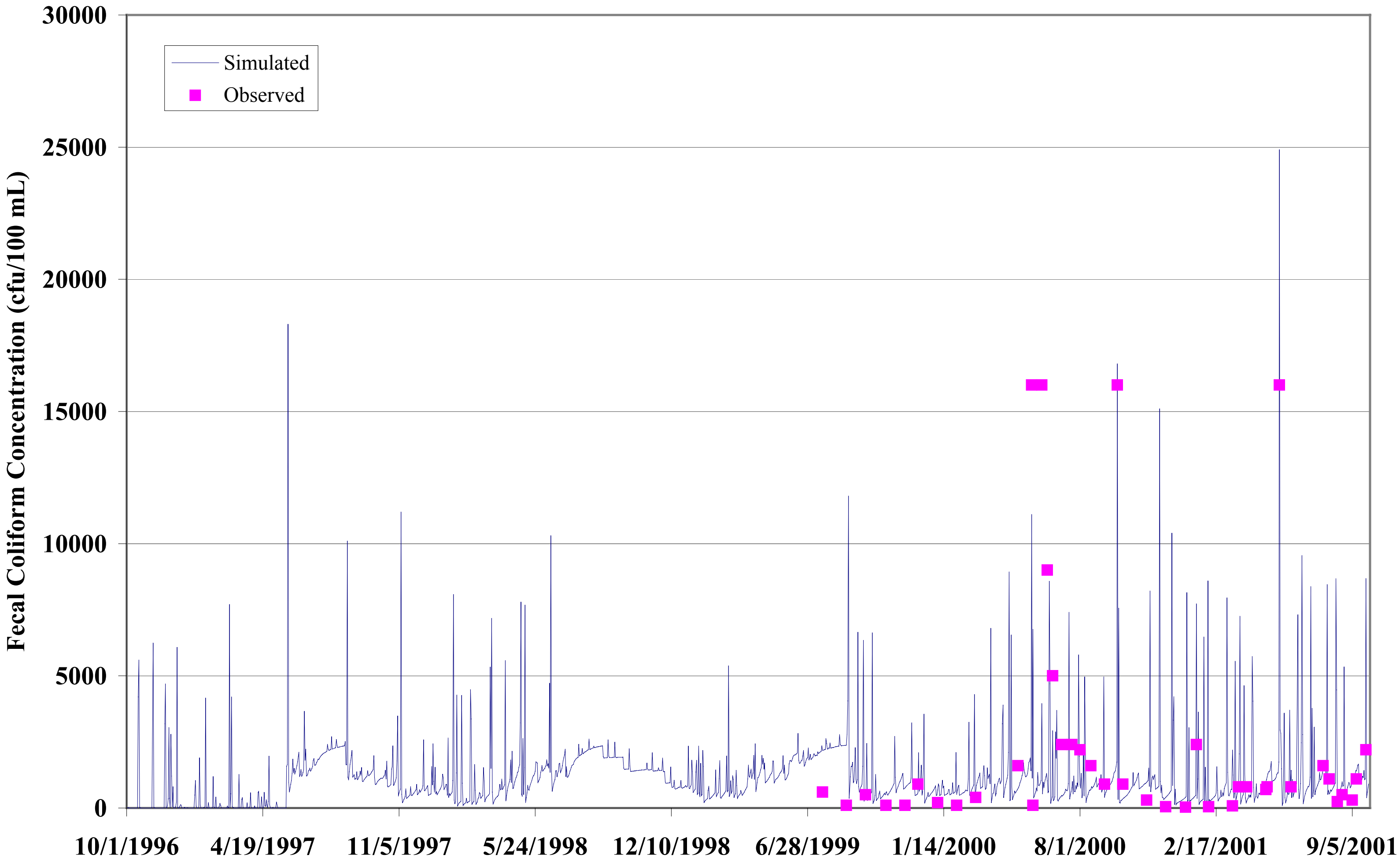


Figure 4.13. Fecal coliform calibration for East reach.

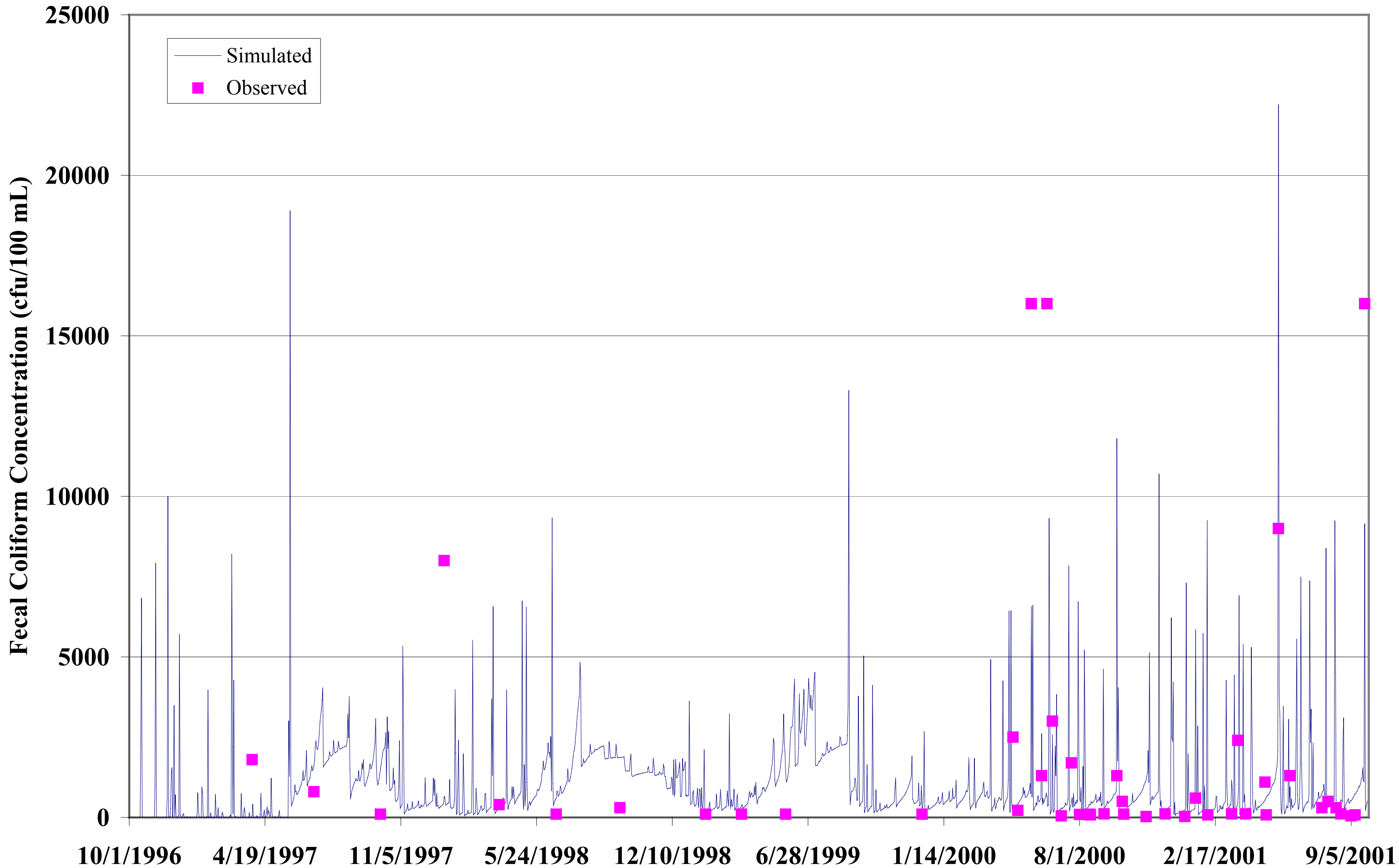


Figure 4.14. Fecal coliform calibration for Main1 reach.

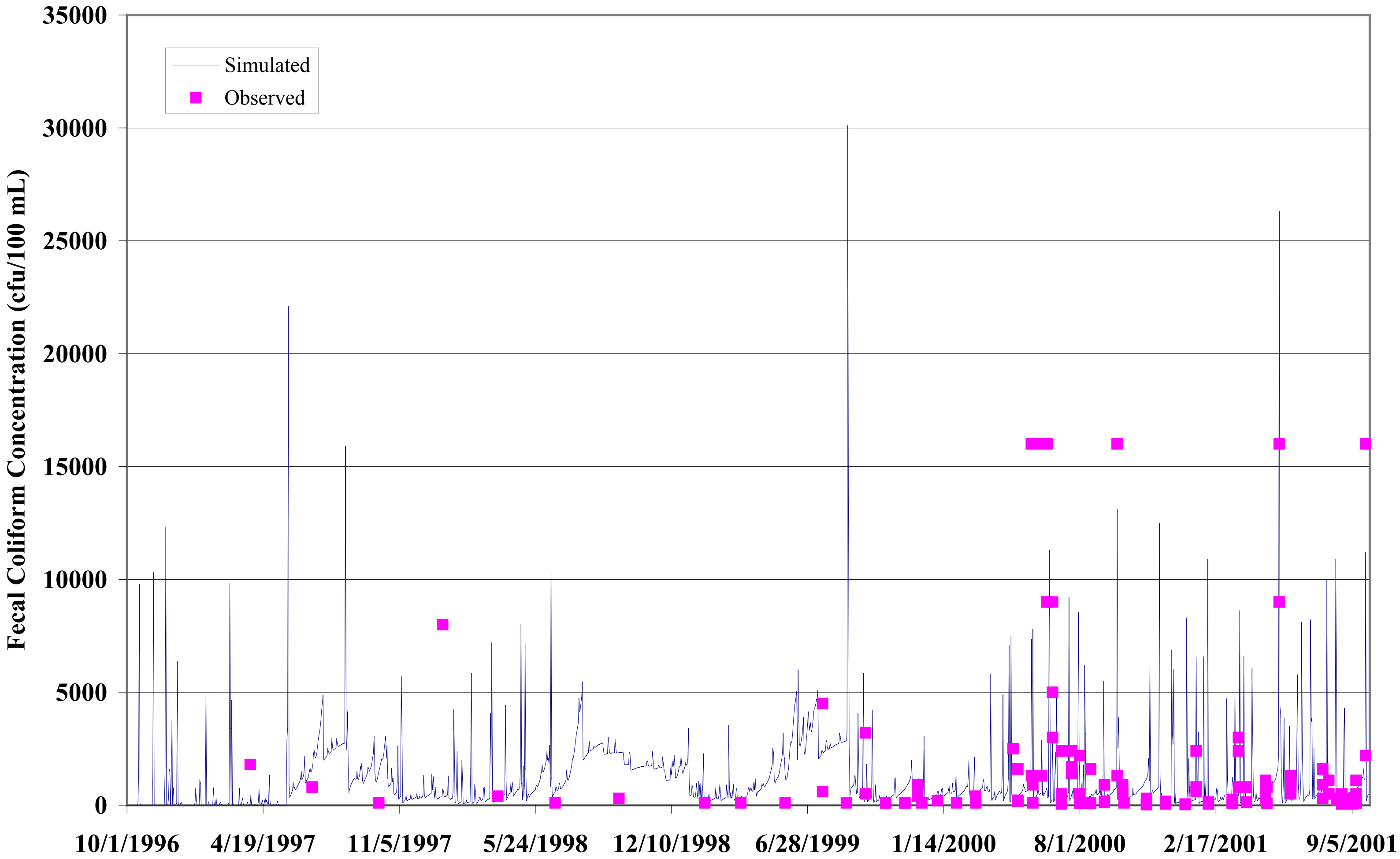


Figure 4.15. Fecal coliform calibration for Thumb Run.

5. LOAD ALLOCATIONS

Total Maximum Daily Loads (TMDLs) are composed of the sum of wasteload allocations (WLAs) determined for point sources and load allocations (LAs) determined for nonpoint sources (USEPA, 2001). The sum of these loads plus a margin of safety (MOS) must not exceed water quality standards (WQSs). A TMDL is defined by the following equation:

$$\text{TMDL} = \Sigma \text{ WLAs} + \Sigma \text{ LAs} + \text{MOS}$$

To develop the Thumb Run fecal coliform TMDL, the existing direct and land-based fecal coliform loadings were reduced within the HSPF water quality model until the 30-day geometric mean standard of 200 cfu/100 mL was met. Various allocation scenarios were evaluated to meet the WQS. The time period selected to determine load allocations was July 1, 1997 to September 30, 2001.

A margin of safety is required to account for the uncertainty in the relationship between pollutant loads and the in-stream water quality. The MOS can be accounted for explicitly or implicitly. A MOS of 5% was incorporated explicitly into the Thumb Run fecal coliform TMDL equation by reducing the target fecal coliform concentration from 200 cfu/100 mL (WQS) to 190 cfu/100 mL.

5.1 Sensitivity Analysis

A sensitivity analysis was performed to ascertain the impact of various assumptions used on the determined loads and to provide a starting point for allocation scenarios. The analysis was performed by adjusting the existing loadings from direct sources and land-based sources up and down by ten and a hundred percent. The numbers of violations of water quality standards in the watershed outlet reach, Main2, were then compared. The resulting percent changes in violations of the 30-day geometric mean and the instantaneous fecal coliform standard are shown in Figures 5.1 and 5.2 respectively.

The sensitivity analysis shows that direct loads to the stream have a significant impact on the number of violations of water quality standards. This indicates that water quality conditions during low flow periods are critical in meeting the 30-day geometric mean water quality standard.

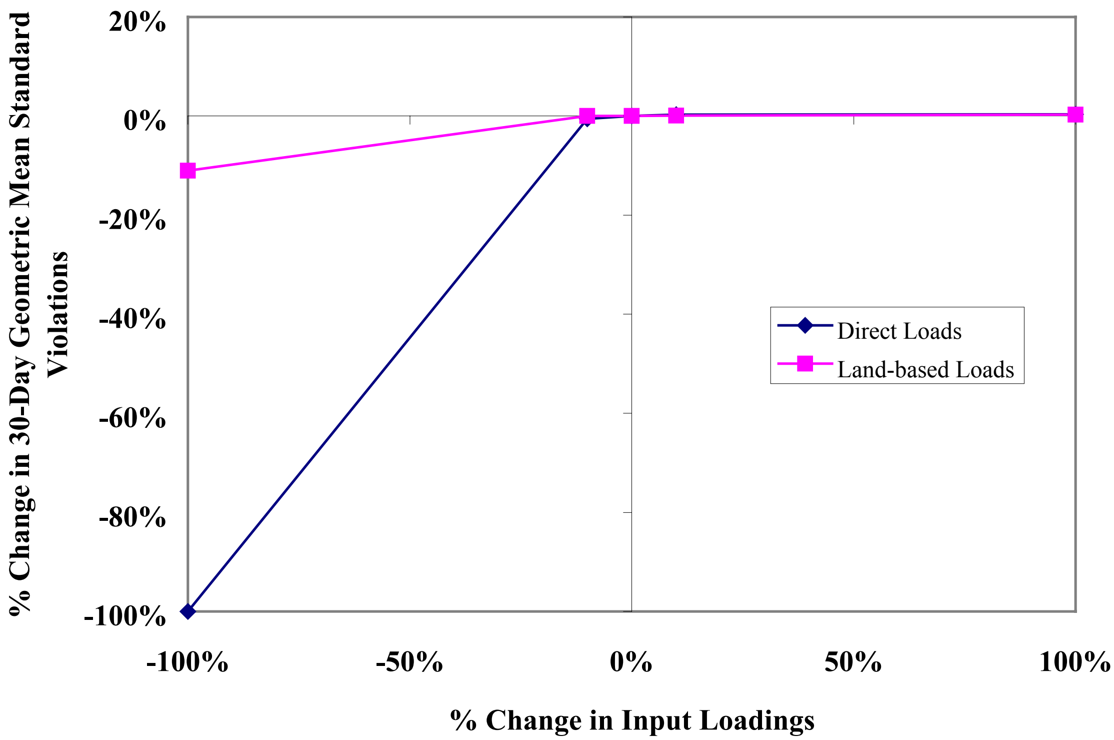


Figure 5.1 Sensitivity analysis for 30-day geometric mean standard violations.

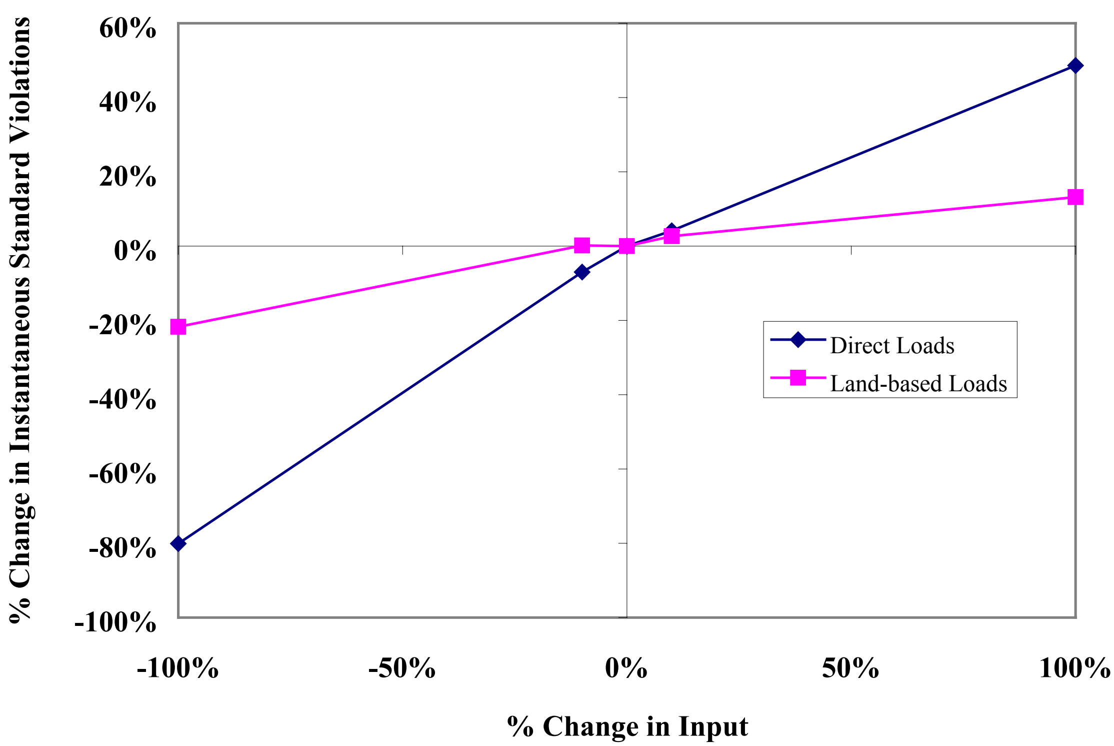


Figure 5.2 Sensitivity analysis for instantaneous standard violations.

5.2 Load Allocation Scenarios

Various load allocation scenarios that will meet water quality standards were evaluated for Thumb Run. Existing loads were reduced in the Thumb Run HSPF model until fecal coliform concentrations in the watershed outlet reach, Main2, met the standards. The Main2 reach generally had the highest simulated fecal coliform levels, so when reductions in source loads were applied to meet water quality standards there, the same reductions also enabled the other four reaches in the watershed to meet the standards. An allocation scenario was considered successful if the running 30-day geometric mean fecal coliform concentration never exceeded 190 cfu/100 mL.

5.2.1 Existing Conditions

The period from July 1, 1997 to September 30, 2001 reflects existing conditions. The HSPF model simulates the fecal coliform concentration in the stream well under these conditions, based on a comparison with observed data. The 30-day geometric mean WQS is violated 100% of the time in the Main2 reach under existing conditions. The instantaneous standard is violated 37% of the time in the Main2 reach under existing conditions. The running 30-day geometric mean fecal coliform concentrations and the instantaneous concentrations for these conditions are shown in Figures 5.3 and 5.4 respectively.

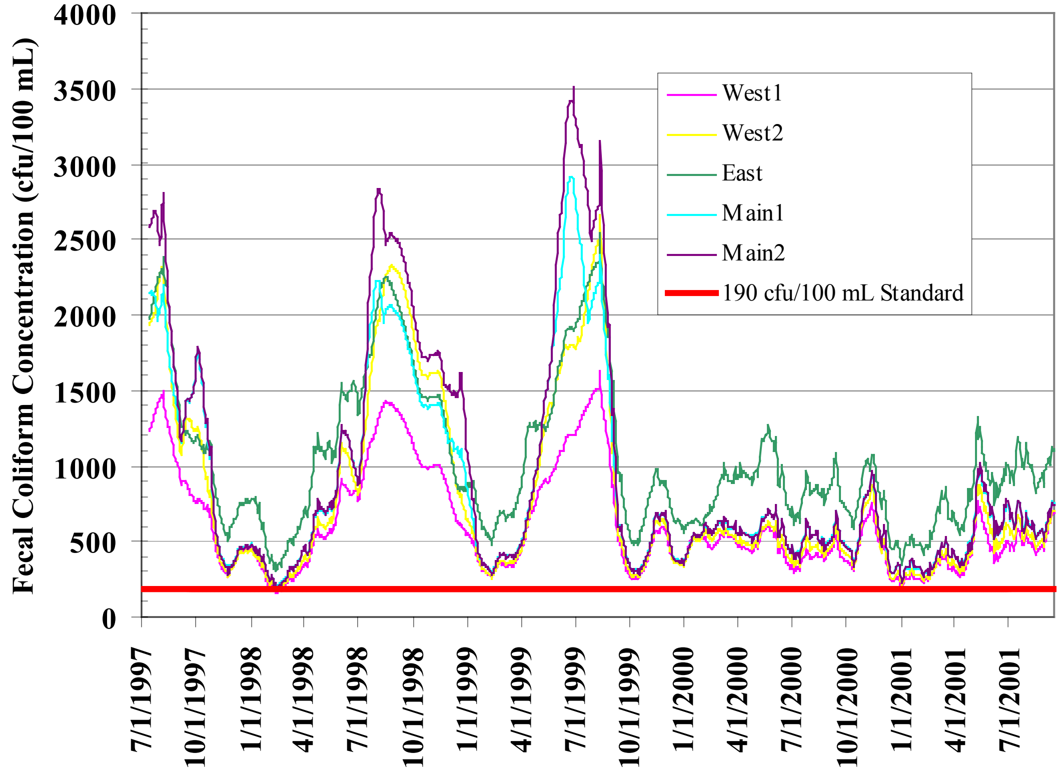


Figure 5.3 Running 30-day geometric mean fecal coliform concentration for existing conditions.

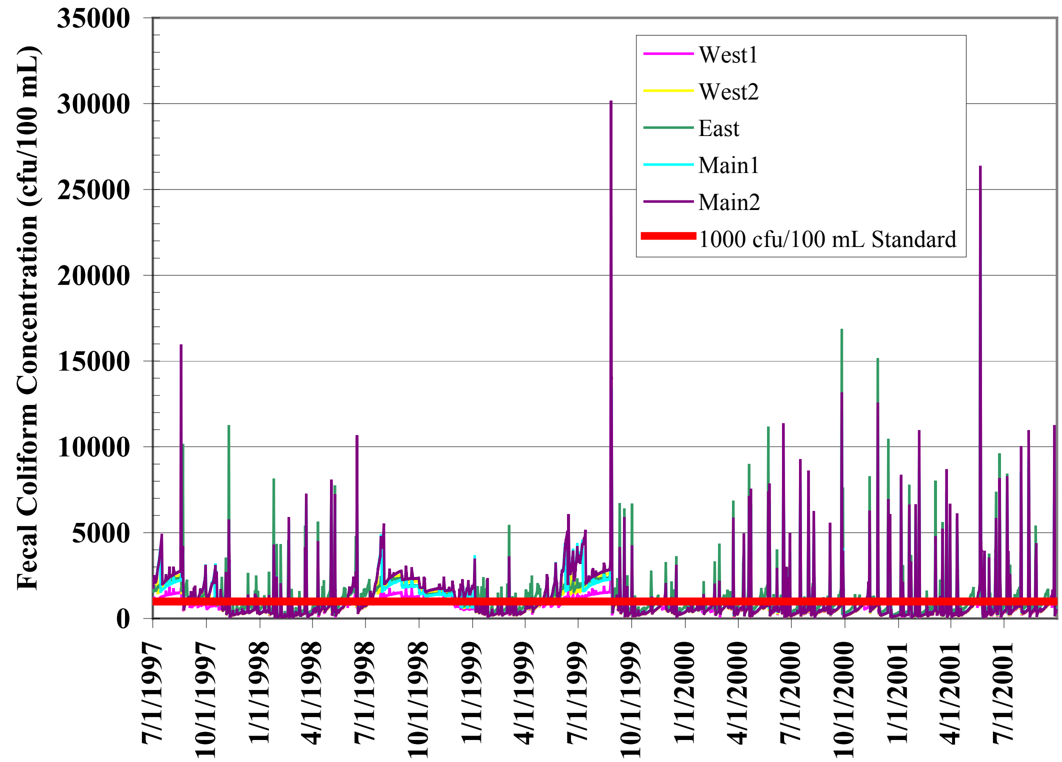


Figure 5.4 Instantaneous fecal coliform concentrations for existing conditions.

5.2.2 Wasteload Allocations

There was only one permitted point source in the Thumb Run Watershed, the Camp Moss Hollow WWTP. The WWTP went off line sometime before August 2000 (exact date unknown). As a result, a wasteload allocation (WLA) has not been made.

5.2.3 Load Allocations

Several allocation scenarios involving the reduction of nonpoint source loads were evaluated to meet water quality standards in Thumb Run. The sensitivity analysis shows that direct loads to the stream have a significant impact on the number of violations of water quality standards (Section 5.1). Livestock account for 96 percent of the direct loads to the stream, so a reduction of livestock direct loads was included in all scenarios. Both direct and land-based loads from failing septic systems were reduced 100 percent in all scenarios because state law prohibits untreated human waste from entering state waters.

The first allocation scenario reduces all wildlife loads by 100 percent. As shown in Table 5.1, this scenario did not reduce the number of 30-day geometric mean standard violations much, so a reduction in wildlife loads is not crucial to meet the standard. Scenario 4 revealed that a 100 percent reduction of the direct livestock load will meet the standard without reducing wildlife or land-based loads. This scenario was chosen as the TMDL allocation scenario.

Scenario 2 was developed to determine what reductions are required to result in less than 10 percent violations of the instantaneous standard (Table 5.2). This goal can be met by reducing septic loads by 100 percent and the livestock direct loads by 75 percent. This allocation can be used in a stage I implementation scenario (Section 6.1.1). Scenario 3 also could be used as a stage I implementation scenario, but it is a less viable option. A significant reduction in land-based loads would be required while the livestock direct load reduction would not change much from Scenario 2.

Table 5.1 Resulting 30-day geometric mean standard violations from allocation scenarios.

Scenario	Percent Reduction in Loading from Existing Condition							Percentage of Days With 30-day GM > 190 cfu/100mL
	Direct Failing Septic Systems	Direct Wildlife Loads	Direct Livestock Loads	Land-based Livestock Loads	Land-based Wildlife Loads	Land-based Pet Loads	Land-based Septic Loads	
Existing Condition	0	0	0	0	0	0	0	100
1	0	100	0	0	100	0	0	100
2	100	0	75	0	0	0	100	61
3	100	0	65	50	0	50	100	61
4	100	0	100	0	0	0	100	0

Table 5.2 Resulting instantaneous water quality standards from allocation scenarios.

Scenario	Percent Reduction in Loading from Existing Condition							Percentage of Days > 1000 cfu/100mL
	Direct Failing Septic Systems	Direct Wildlife Loads	Direct Livestock Loads	Land-based Livestock Loads	Land-based Wildlife Loads	Land-based Pet Loads	Land-based Septic Loads	
Existing Condition	0	0	0	0	0	0	0	37
1	0	100	0	0	100	0	0	36
2	100	0	75	0	0	0	100	10
3	100	0	65	50	0	50	100	9
4	100	0	100	0	0	0	100	7

Figure 5.5 compares the 30-day geometric mean standard results for exiting conditions to the successful TMDL allocation scenario (Scenario 4). Existing conditions are consistently above the 190 cfu/100 mL standard, while the successful TMDL allocation scenario is always below.

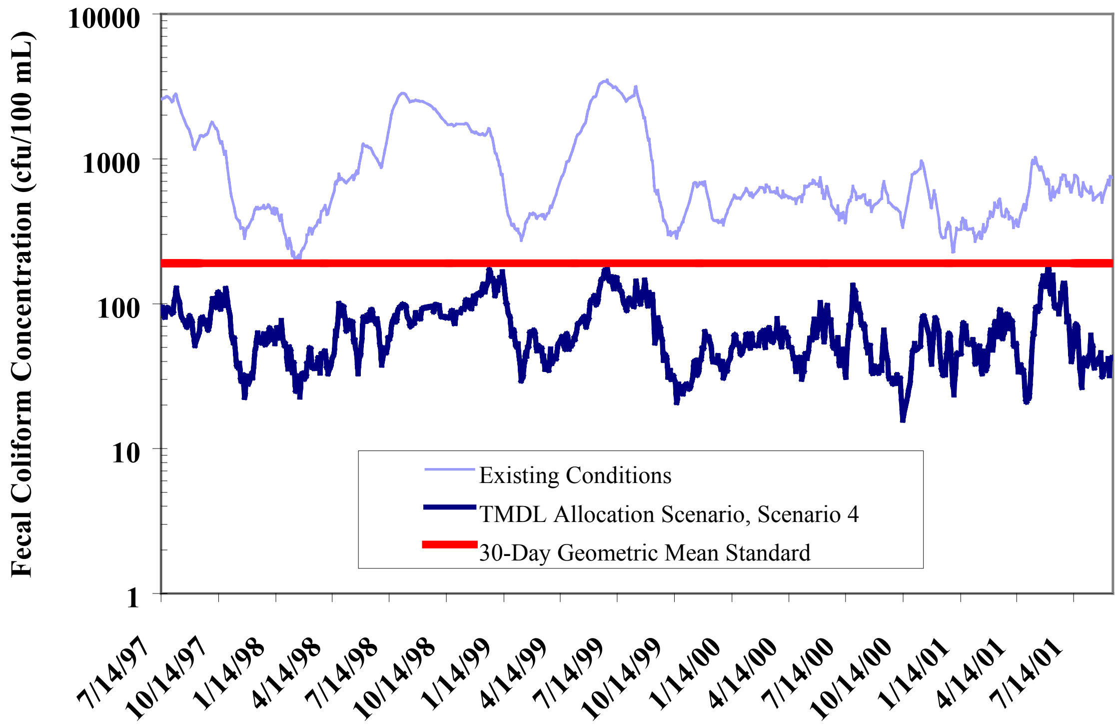


Figure 5.5 30-day geometric mean results for existing conditions and successful allocation scenario.

5.3 Summary of Load Allocations

Annual nonpoint source loadings for existing conditions and the TMDL allocation scenario are shown in Table 5.3.

Table 5.3 Nonpoint source load reductions to Thumb Run for Scenario 4.

Source		Subwatershed					Total
		West1	West2	East	Main1	Main2	
Direct Load - Failing Septic	**Existing Load (x 10^{12} cfu/year)**	1.96	-	-	-	-	1.9564
	Allocated Load (x 10^{12} cfu/year)	0	-	-	-	-	0.0000
	% Reduced	100%	-	-	-	-	100%
Direct Load - Wildlife	**Existing Load (x 10^{12} cfu/year)**	1.8004	1.7894	1.2706	0.7756	1.5723	7.2084
	Allocated Load (x 10^{12} cfu/year)	1.8004	1.7894	1.2706	0.7756	1.5723	7.2084
	% Reduced	0%	0%	0%	0%	0%	0%
Direct Load - Livestock	**Existing Load (x 10^{12} cfu/year)**	34.9	46.5	52.3	24.4	41.0	199.0
	Allocated Load (x 10^{12} cfu/year)	0.00	0.00	0.00	0.00	0.00	0.00
	% Reduced	100%	100%	100%	100%	100%	100%
Land-based Load - Failing Septic	**Existing Load (x 10^{12} cfu/year)**	5.0	6.8	5.3	6.8	7.5	31.3
	Allocated Load (x 10^{12} cfu/year)	0.00	0.00	0.00	0.00	0.00	0.00
	% Reduced	100%	100%	100%	100%	100%	100%

The possibility of future growth in the Thumb Run watershed was accounted for in the TMDL. The watershed, which is highly agricultural and forested, is not predicted to be developed significantly beyond existing conditions (personal communication with RRRC). Therefore, any future growth will likely be accounted for in the margin of safety.

A summary of the fecal coliform allocation loads for the Thumb Run TMDL is provided in Table 5.4.

Table 5.4 Annual fecal coliform loadings (cfu/year) for the Thumb Run TMDL

Parameter	ΣWLA	ΣLA	MOS (5%)	TMDL
Fecal Coliform	0	13,990 x 10^{12}	700 x 10^{12}	14,690 x 10^{12}

6. IMPLEMENTATION AND PUBLIC PARTICIPATION

6.1 TMDL Implementation

The Commonwealth intends for this TMDL to be implemented through best management practices (BMPs) in the watershed. Implementation will occur in stages. The benefits of staged implementation are, 1) as stream monitoring continues to occur, it allows for water quality improvements to be recorded as they are being achieved; 2) it provides a measure of quality control, given the uncertainties which exist in any model; 3) it provides a mechanism for developing public support; 4) it helps to ensure the most cost effective practices are implemented initially, and 5) it allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard.

While specific stage I goals for BMP implementation will be established as part of the implementation plan development process, some general guidelines and suggestions are outlined below.

In general, the Commonwealth intends for the required reductions to be implemented in an iterative process that addresses the sources with the largest impact on water quality first. For example, the most promising management practice in agricultural areas of the watershed is livestock exclusion from streams. This has been shown to be very effective in lowering fecal coliform concentrations in streams, both from the cattle deposits themselves and from additional buffering in the riparian zone. Additionally, reducing the human bacteria loading from failing septic systems and straight pipes should be a focus during the first stage because of the health implications of these sources.

Since the TMDL consists solely of nonpoint source load allocations (LA), VADCR will have the lead for the development of the implementation plan. Watershed stakeholder cooperation is vital to the success of the implementation plan, so their input and involvement will be requested during the development of the plan. Several state agencies including regional and local offices of VADEQ and VADCR, will also support the development of the implementation plan.

6.1.1 Stage I Implementation Goal

Allocation scenarios were evaluated that would meet a stage I goal of less than 10 percent violations of the instantaneous standard. This goal can be met by reducing the failing septic systems and straight pipe by 100 percent and the livestock direct loads by 75 percent (Scenario 2).

Another scenario was evaluated that could meet this same stage I goal (Scenario 3). This scenario requires 100 percent reduction in loads from the failing septic systems, 75 percent reduction of direct deposition to the stream from livestock, and 50 percent reduction in land loads from livestock and pets. This scenario is a less viable option than Scenario 2 because a large reduction of land-based loads from livestock would be required with only a small change in the reduction of direct loads from livestock. This scenario helps clarify the benefit to water quality of reducing the direct loads to the stream from livestock.

Table 6.1 shows the required nonpoint source load reductions required to meet the stage I goal (Scenario 2).

Table 6.1 Nonpoint source load reductions to Thumb Run for Scenario 2.

Source		Subwatershed					Total
		West1	West2	East	Main1	Main2	
Direct Load - Failing Septic	**Existing Load (x 10^{12} cfu/year)**	1.96	-	-	-	-	1.9564
	Allocated Load (x 10^{12} cfu/year)	0	-	-	-	-	0.0000
	% Reduced	100%	-	-	-	-	100%
Direct Load - Wildlife	**Existing Load (x 10^{12} cfu/year)**	1.8004	1.7894	1.2706	0.7756	1.5723	7.2084
	Allocated Load (x 10^{12} cfu/year)	1.8004	1.7894	1.2706	0.7756	1.5723	7.2084
	% Reduced	0%	0%	0%	0%	0%	0%
Direct Load - Livestock	**Existing Load (x 10^{12} cfu/year)**	34.9	46.5	52.3	24.4	41.0	199.0
	Allocated Load (x 10^{12} cfu/year)	8.71	11.62	13.07	6.10	10.25	49.76
	% Reduced	75%	75%	75%	75%	75%	75%
Land-based Load - Failing Septic	**Existing Load (x 10^{12} cfu/year)**	5.0	6.8	5.3	6.8	7.5	31.3
	Allocated Load (x 10^{12} cfu/year)	0.00	0.00	0.00	0.00	0.00	0.00
	% Reduced	100%	100%	100%	100%	100%	100%

6.1.2 Follow-Up Monitoring

The Department of Environmental Quality will continue to monitor Thumb Run in accordance with its ambient monitoring program. VADEQ and VADCR will continue to use data from these monitoring stations to evaluate reductions in fecal bacteria counts and the effectiveness of the TMDL in attaining and maintaining water quality standards.

6.1.3 Regulatory Framework

The goal of this TMDL is to establish a three-step path that will lead to expeditious attainment of water quality standards. The first step in this process was to develop load reductions for sources of fecal coliform bacteria to Thumb Run Creek using a watershed model, and is the purpose of this report. The second step is to develop a TMDL implementation plan, and the final step is to implement the TMDL and attain water quality standards.

Section 303(d) of the Clean Water Act (CWA) and current USEPA regulations do not require the development of implementation strategies. However, including implementation plans as a TMDL requirement has been discussed for future federal regulations. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQ MIRA) directs VADEQ in section 62.1-44.19.7 to "develop and implement a plan to achieve fully supporting status for impaired waters". The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated cost, benefits and environmental impact of addressing the impairments. USEPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, time line, legal or regulatory controls, time required to attain water quality standards, monitoring plan and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ, VADCR and other cooperating agencies.

Once developed, VADEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan, in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between USEPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to USEPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

6.1.4 Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. In response to the federal Clean Water Action Plan, Virginia developed a Unified

Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted towards TMDL implementation and watershed restoration. Other funding sources for implementation include the USDA's Conservation Reserve Enhancement Program, the State Revolving Loan Program, the Virginia Water Quality Improvement Fund, and the Environmental Quality Incentives Program.

6.2 Public Participation

The development of the Thumb Run TMDL would not have been possible without public participation. The first public meeting was held in Orlean on August 1, 2001 to discuss the process for TMDL development, 18 people attended. Copies of the presentation materials were available for public distribution. The meeting was public noticed in the *Virginia Register*. A public meeting notice was published in the Fauquier Citizen on July 19 and 26, 2001, and in the Fauquier Times Democrat on the same dates. There was a 30 day-public comment period and no written comments were received.

The second public meeting was held in Orlean on November 8, 2001 to discuss the source assessment input, bacterial source tracking, and model calibration data**,** 30 people attended. Copies of the presentation materials were available for public distribution. The meeting was public noticed in the *Virginia Register*. A public meeting notice was also published in the Fauquier Times-Democrat on October 31, 2001. A mailing was also sent out to 639 boxholders and rural route residents in the Thumb Run watershed. The mailing consisted of a postcard indicating the date, time and location of the public meeting and encouraging the public to attend. There was a 30 day-public comment period and no written comments were received.

The third public meeting was held in Orlean on April 4, 2002 to discuss the draft TMDL, 26 people attended. Copies of the draft TMDL were available for public distribution. The meeting was public noticed in the *Virginia Register*. A public notice was published in the Fauquier Times-Democrat on March 27, 2002. A mailing was also sent out to 654 boxholders and rural route residents in the Thumb Run watershed. The mailing consisted of a postcard indicating the date, time and location of the public meeting and encouraging the public to attend. There was a 30-day public comment period and no written comments were received.

KEY TO ACRONYMS

ARA	Antibiotic Resistance Analysis
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BST	Bacterial Source Tracking
BMP	Best Management Practices
CFR	Code of Federal Regulations
CFU	Colony-forming Units
CWA	Clean Water Act
DO	Dissolved Oxygen
ENT	Enteroccocci
FC	Fecal Coliform Bacteria
GIS	Geographic Information System
HSPF	Hydrologic Simulation Program-Fortran
LA	Load Allocation (for nonpoint sources in TMDLs)
LC	Load Capacity
MGD	Million Gallons per Day
MOS	Margin of Safety
MPN	Most Probable Number
NPDES	National Pollution Discharge Elimination System
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
PCS	Permit Compliance System
POTW	Publicly-owned Treatment Works
PS	Point Source
SDWA	Safe Drinking Water Act
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
VADACS	Virginia Department of Agriculture and Consumer Services
VADCR	Virginia Department of Conservation and Recreation
VADEQ	Virginia Department of Environmental Quality
VADGIF	Virginia Department of Game and Inland Fisheries
VDH	Virginia Department of Health
VPDES	Virginia Pollutant Discharge Elimination System

WLA	Wasteload Allocation (for point sources in TMDLs)
WQIA	Water Quality Improvement Act
WQS	Water Quality Standard
WWTP	Wastewater Treatment Plant

GLOSSARY

Note: (Entries in italics are from USEPA, 2001; all others are from MapTech, Inc., 2001)

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Advection. *Bulk transport of the mass of discrete chemical or biological constituents by fluid flow within a receiving water. Advection describes the mass transport due to the velocity, or flow, of the waterbody.*

Allocations. *Allocations are that portion of a receiving water's loading capacity that is attributed to one of its existing or future sources (nonpoint or point) of pollution or to natural background sources. (Wasteload allocation (WLA) is that portion of the loading capacity allocated to an existing or future point source and a load allocation (LA) is that portion allocated to an existing or future nonpoint source or to natural background source. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Concentration of water quality constituent as measured within the waterbody.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antibiotic Resistance Analysis (ARA). A method of bacterial source tracking that involves the isolation of indicator bacteria from different known fecal samples, as well as from unknown water samples.

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity. *The amount of pollutant load that can be discharged to a specific waterbody without exceeding water quality standards. Assimilative capacity is used to define the* *ability of a waterbody to naturally absorb and use a discharges substance without impairing water quality or harming aquatic life.*

Bacteria. *Single-celled microorganisms that lack a fully-defined nucleus and contain no chlorophyll. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources). *A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.*

Best management practices (BMPs). *Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Biosolids. Biologically treated solids originating from municipal waste water treatment plants.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is section 303(d), which establishes the TMDL program.*

Coliform bacteria. *See Total coliform bacteria.*

Concentration. *Amount of a substance or material in a given unit volume of solution. Usually measured in milligrams per liter (mg/l) or parts per million (ppm).*

Confluence. The point at which a river and its tributary flow together.

Contamination. *Act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Cost-share program. *Program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs are paid by the producer.*

Critical condition. *The combination of environmental factors that results in just meeting the water quality criterion and has an acceptably low frequency of occurrence.*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Cryptosporidium. *See protozoa.*

Decay. *Gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition. *Metabolic breakdown of organic materials; the by-products formation releases energy and simple organics and inorganic compounds. (See also Respiration.)*

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Deterministic model. *A model that does not include built-in variability: same input will always equal the same output.*

Die-off rate. *The first-order decay rate for bacteria, pathogens, and viruses. Die-off depends on the particular type of water body (i.e. stream, estuary , lake) and associated factors that influence mortality.*

Dilution. *Addition of less concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge permits (NPDES). *A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. It is called the NPDES because the permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion. *The spreading of chemical or biological constituents, including pollutants, in various directions from a point source, at varying velocities depending on the differential instream flow characteristics.*

Dissolved oxygen (DO). *The amount of oxygen that is dissolved in water. It also refers to a measure of the amount of oxygen available for biochemical activity in a waterbody, and as an indicator of the quality of that water.*

Dynamic model. *A mathematical formulation describing the physical behavior of a system or a process and its temporal variability.*

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent limitation. *Restrictions established by a state or USEPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints that are commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance. A measurement* *endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints.*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Enteric. *Of or within the gastrointestinal tract.*

Enterococci (ENT). *A subgroup of the fecal streptococci that includes S. faecalis and S. faecium. The enterococci are differentiated from other streptococci by their ability to grow in 6.5 percent sodium chloride, at pH 9.6, and at 10 C and 45 C. Enterococci are a valuable bacterial indicator for determining the extent of fecal contamination of recreational surface waters.*

Epidemiology. *All the elements contributing to the occurrence or non-occurrence of a disease in a population; ecology of a disease.*

Escherichia coli. *A subgroup of the fecal coliform bacteria. E. coli is part of the normal intestinal flora in humans and animals and is, therefore, a direct indicator of fecal contamination in a waterbody. The O157 strain, sometimes transmitted in contaminated waterbodies, can cause serious infection resulting in gastroenteritis. See Fecal coliform bacteria.*

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Existing use. *Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).*

Fate of pollutants. *Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transportation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Fecal coliform bacteria (FC). *A subset of total coliform bacteria that are present in the intestines or feces of warm-blooded animals. They are often used as indicators of the sanitary quality of* *water. They are measured by running the standard total coliform test at an elevated temperature (44.5 °C). Fecal coliform is approximately 20 percent of total coliform. See also Total coliform bacteria.*

Fecal streptococci. *These bacteria include several varieties of streptococci that originate in the gastrointestinal tract of warm-blooded animals such as humans (Streptococcus faecalis) and domesticated animals such as cattle (Streptococcus bovis) and horses (Streptococcus equinus).*

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

First-order kinetics. *The type of relationship describing a dynamic reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

Gastroenteritis. *An inflammation of the stomach and the intestines.*

Geochemical. *Refers to chemical reactions related to earth materials such as soil, rocks, and water*

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

Giardia lamblia. *See protozoa.*

GIS (Geographic Information System). A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth.

Gradient. *The rate of decrease (or increase) of one quantity with respect to another; for example, the rate of decrease of temperature with depth in a lake.*

Groundwater. *The supply of fresh water found beneath the earth s surface, usually in aquifers, which supply wells and springs. Because groundwater is a major source of drinking water, there* *is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

Hot Spots. *Locations in a waterbodies or sediments where hazardous substances have accumulated to levels which may pose risks to aquatic life, wildlife, fisheries, or human health.*

HSPF (Hydrological Simulation Program – Fortran). A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrologic cycle. *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology. *The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *Measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *Organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Infectivity. *Ability to infect a host.*

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

Insolation. *Exposure to the sun's rays.*

Interflow. Runoff which travels just below the surface of the soil.

Land application. *Discharge of wastewater onto the ground for treatment or reuse. (See: irrigation)*

Load, Loading, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving water s loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished. (40 CFR 130.2(g))*

Loading capacity (LC). *The greatest amount of loading that a water can receive without violating water quality standards.*

Low-flow. *Stream flow during time periods where no precipitation is contributing to runoff to the stream and contributions from groundwater recharge are low. Low flow results in less water available for dilution of pollutants in the stream. Due to the limited flow, direct discharges to the stream dominate during low flow periods. Exceedences of water quality standards during low flow conditions are likely to be caused by direct discharges such as point sources, illicit discharges, and livestock or wildlife in the stream.*

Margin of Safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by USEPA either individually or in state/USEPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mathematical model. *A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one, or* *more, individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

MGD (Million gallons per day). A unit of water flow, whether discharge or withdraw.

Meningitis. *Inflammation of the meninges, especially as a result of infection by bacteria or viruses.*

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those which restore, enhance, create, or replace damaged ecosystems.*

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under Sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural background levels. *Natural background levels represent the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nonpoint source (NPS). *Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

NRCS. *Natural Resources Conservation Service.*

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substance synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Outfall. *Point where water flows from a conduit, stream, or drain.*

Oxygen demand. *Measure of the dissolved oxygen used by a system (microorganisms) in the oxidation of organic matter. See also biochemical oxygen demand.*

Partition coefficients. *Chemicals in solution are partitioned into dissolved and particulate adsorbed phase based on their corresponding sediment-to-water partitioning coefficient.*

Pathogen. *Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g., pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by USEPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system which contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased approach. *Under the phased approach to TMDL development, LAs and WLAs are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Point source (PS). *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste* *treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water. (CWA Section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Protozoa. *Single-celled organisms that reproduce by fission and occur primarily in the aquatic environment. Waterborne pathogenic protozoans of primary concern include Giardia lamblia and Cryptosporidium, both of which affect the gastrointestinal tract.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by USEPA or states (e.g., a Federal Register notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Raw sewage. *Untreated municipal sewage.*

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, groundwater formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Residence time. *Length of time that a pollutant remains within a section of a waterbody. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration. *Return of an ecosystem to a close approximation of its condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. Theses areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Runoff. *That part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Roughness coefficient. *A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

Safe Drinking Water Act (SDWA). *The Safe Drinking Water Act authorizes USEPA to set national health-based standards for drinking water to protect against both naturally occurring and man-made contaminants that may be found in drinking water. USEPA, states, and water systems then work together to make sure these standards are met.*

Scour. *To abrade and wear away. Used to describe the weathering away of a terrace or diversion channel or streambed. The clearing and digging action of flowing water, especially the downward erosion by stream water in sweeping away mud and silt on the outside of a meander or during flood events.*

Sediment. *Organic or inorganic material often suspended in liquid that eventually settles to the bottom.*

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a system of tile lines or a pit for disposal of the liquid effluent (sludge) that remains after decomposition of the solids by bacteria in the tank; must be pumped out periodically.*

Sewer. *A channel or conduit that carries wastewater and stormwater runoff from the source to a treatment plant or receiving stream. "Sanitary" sewers carry household, industrial, and commercial waste. "Storm" sewers carry runoff from rain or snow. "Combined" sewers handle both.*

Simulation. *Refers to the use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04); degrees (2 degrees 18 minutes), or percent (4 percent).*

Spatial segmentation. *A numerical discretization of the spatial component of system into one or more dimensions; forms the basis for application of numerical simulation models.*

Stakeholder. *Those parties likely to be affected by the TMDL.*

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Storm runoff. *Stormwater runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or waterbodies or is routed into a drain or sewer system.*

Stormwater. *The portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, interflow, channels or pipes into a defined surface water channel, or a constructed infiltration facility.*

Stressor. *Any physical, chemical, or biological entity that can induce an adverse response.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other groundwater collectors directly influenced by surface water.*

Suspended solids or load. *Organic and inorganic particles (sediment) suspended in and carried by a fluid (water). The suspension is governed by the upward components of turbulence, currents, or colloidal suspension. Suspended sediment usually consists of particles <0.1 mm, although size may vary according to current hydrological conditions. Particles between 0.1 mm and 1 mm may move as suspended or bedload.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g., 15-minutes, 1-hour, 1-day).

Topography. *The physical features of a surface area including relative elevations and the position of natural and man-made features.*

Total coliform bacteria. *A particular group of bacteria, found in the feces of warm-blooded animals, that are used as indicators of possible sewage pollution. They are characterized as aerobic or facultative anaerobic, gram-negative, nonspore-forming, rod-shaded bacteria which ferment lactose with gas formation within 48 hours at 35° . Note that many common soil bacteria are also total coliforms, but do not indicate fecal contamination. See also fecal coliform bacteria.*

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, and a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

Tributary. *A lower order stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Urban runoff. *Water containing pollutants like oil and grease from leaking cars and trucks; heavy metals from vehicle exhaust; soaps and grease removers; pesticides from gardens; domestic animal waste; and street debris, which washes into storm drains and enters surface waters.*

USEPA. United States Environmental Protection Agency.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VADGIF. Virginia Department of Game and Inland Fisheries.

Validation (of a model). *Process of determining how well the mathematical representation of the physical processes of the model code describes the actual system behavior.*

VDH. Virginia Department of Health.

Verification (of a model). *Testing the accuracy and predictive capabilities of the calibrated model on a data set independent of the data set used for calibration.*

Virus. *Submicroscopic pathogen consisting of a nucleic acid core surrounded by a protein coat. Requires a host in which to replicate (reproduce).*

Wasteload allocation (WLA). *The portion of a receiving water s loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant.*

Wastewater treatment. *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water in order to remove, reduce, or neutralize contaminants.*

Water quality. *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality criteria. *Elements of state water quality standards expressed as constituent concentrations, levels, or narrative statement, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use.*

Water quality standard (WQS). *State or federal law or regulation consisting of a designated use or uses for the waters of the United States, water quality criteria for such waters based upon such uses, and an antidegradation policy and implementation procedures. Water quality standards protect the public health or welfare, enhance the quality of water and serve the purposes of the Clean Water Act.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WWTP. Wastewater Treatment Plant.

WQIA. Water Quality Improvement Act.

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APPENDIX A. BASINS WDM FILES

Excerpt from BASINS 2.0 Manual (Lahlou, et al., 1998)

(note: WDMs for BASINS 3.0 have not been released, so WDMs for BASINS 2.0 were used with BASINS 3.0)

WDM files, providing meteorological coverage for the United States and U.S. territories were prepared for BASINS 2.0 through the following steps:

1. Data were obtained from the following sources.

a. Hourly observed precipitation data for the United States and U.S. territories were obtained from the National Climatic Data Center (NCDC) Hourly and Fifteen Minute Precipitation database, compiled by EarthInfo, Inc. This four CD-ROM data set contains precipitation data from NCDC's TD-3240 file. Included in the database are over 6000 weather stations with recorded precipitation for the general period of 1948-1995.

b. Hourly surface observation data for the United States and U.S. territories were obtained from NCDC's Solar and Meteorological Surface Observational Network (SAMSON) and Hourly U.S. Weather Observations 1990-1995 (HUSWO) databases. SAMSON is a three CD-ROM data set containing both observational and modeled hourly solar radiation data, as well as hourly cloud cover, drybulb temperature, dewpoint temperature, and wind movement data from 237 NWS stations for the period of 1961-1990. The HUSWO data set, contained on a single CD-ROM, updates meteorological data from the SAMSON data set, excluding solar radiation data for the period of 1990-1995.

c. The remaining parameters—potential evapotranspiration, evaporation, and solar radiation (for the period of 1991-1995)—were calculated using METCMP.

2. A coverage of WDM weather stations for BASINS 2.0 was created in ArcView using latitude and longitude coordinates from selected weather stations included in NCDC's Hourly and Fifteen Minute Precipitation database. These stations, which included the precipitation data, were then assigned meteorological data from the set of NWS stations available from the SAMSON data set. The selection of weather stations used to create the WDM station coverage, as well as the assignment of meteorological data to these stations, was performed in ArcView using an array of GIS coverages. This was done to provide a spatially distributed coverage of the United States and U.S. territories, based on information relating to annual rainfall, climatic divisions in the

conterminous United States, completeness of weather station data, elevation, physical divisions in the conterminous United States, and proximity to NWS stations. A complete list of the ArcView coverages used in the selection of WDM weather stations is detailed in B.2.2.a. The resulting ArcView coverage consisted of 477 WDM weather stations for the United States and U.S. territories. This coverage was then divided by EPA regions. EPA regional coverage included WDM weather stations that closely bordered the region or were contained within HUCs intersecting the region. A complete list of the WDM stations is included in B.2.2.b.

3. The data were extracted and converted into a sequential time series format.

a. Hourly precipitation data were extracted from the EarthInfo, Inc., NCDC Hourly and Fifteen Minute Precipitation database by exporting data for individual stations into ASCII tabular formatted files. These raw data were then preprocessed through a FORTRAN program for conversion to a sequential file format. Missing precipitation data were assigned appropriate values. A value of 0.0 was normally used where no reading was available. Preprocessing also included the identification and editing of rainfall accumulation values within the file. Rainfall accumulation values occurred where hourly precipitation values for a time period were not recorded.

The following assumptions and corresponding actions refer to rainfall accumulation data.

- If an accumulation value was recorded for an accumulation period of ≤ 24 hours, then the accumulation value was divided by the number of hours in the period.
- If the resulting hourly value was ≥ 0.01 in. and < 2.0 in., then each hour in the accumulation period was given the resulting hourly value. The state code, station identifier, accumulation period end date and hour, accumulation value, number of hours in the accumulation period, resulting hourly value, and "Value Distributed" were listed in a text file (BASINS\DATA\MET-DATA\<ST>.TXT).
- If the resulting hourly value was < 0.01 in., then each hour in the accumulation period was given a value of 0.0 in. The accumulation value (which in all situations will be ≤0.24 in.) was left unchanged, i.e. the original recorded accumulation value was used. The state code, station identifier, accumulation period end date and hour, accumulation value, number of hours in the accumulation period, resulting hourly value of 0.0 in., and "Calculated Value < .01, Accumulated Value Reported" were listed in a text file (BASINS\DATA\MET-DATA\<ST>.TXT).

- If the resulting hourly value was ≥ 2.0 in., then each hour in the accumulation period was given a value of 0.0 in. The accumulation value is additionally deleted from the record. This prevented the existence of a large spike precipitation value in the data (which in all situations was ≥ 4.0 in. for the accumulation period). The state code and station identifier number, the accumulation period end date and hour, accumulation value, number of hours in the accumulation period, and "Calculated Value > 2.0, Accumulated Value Deleted" were listed in a text file (BASINS\DATA\MET-DATA\<ST>.TXT).
- If an accumulation value was recorded for an accumulation period of > 24 hours, then the accumulation value was not distributed evenly over the accumulation period.
- If the accumulation value was < 2.0 in., then the value was not changed. The state code and station identifier number, the accumulation period end date and hour, accumulation value, number of hours in the accumulation period, and "Accumulation Interval > 24 hrs and Observed Value < 2 Accumulated Value Reported" were listed in a text file (BASINS\DATA\MET-DATA\<ST>.TXT).
- If the accumulation value was ≥ 2.0 in., then the value was deleted from the record. The state code and station identifier number, the accumulation period end date and hour, accumulation value, number of hours in the accumulation period, and "Accumulation Interval > 24 hrs and Observed Value > 2 Accumulated Value Deleted" were listed in a text file (BASINS\DATA\MET-DATA\<ST>.TXT).

b. Hourly meteorological data were extracted from NOAA's Solar and Meteorological Surface Observational Network (SAMSON) database by exporting the yearly data files for an individual station from a CD ROM and unzipping them into an ASCII text file. These raw data were then preprocessed through a FORTRAN program to organize the data into a sequential time series format, convert the data into U.S. units, and calculate daily variables required by METCMP for the estimation of Solar Radiation (for the years 1991-95), Pan Evaporation, and Potential Evapotranspiration.

Hourly data files included:

- ATEM average hourly air temperature
- WIND average hourly wind speed
- SOLR total hourly solar radiation
- DEWP average hourly dew point temperature
- CLOU average hourly cloud cover

Daily data files included:

- TMAX maximum daily air temperature
- TMIN minimum daily air temperature
- DWND total daily wind movement
- DSOL total daily solar radiation
- DPTP average daily dew point temperature
- DCLO average daily cloud cover

Due to the nature of the data, missing data was assigned the previously recorded value.

Data conversions included:

- ATEM and DEWP from °C to °F
- WIND from m/s to mph
- SOLR from Wh/m^2 to Langleys ($calories/cm^2$)

Data calculations included:

- TMAX from ATEM
- TMIN from ATEM
- DCLO from CLOU
- DPTP from DEWP
- DSOL from SOLR
- DWND from WIND

4. WDM, .inf, and .uci files were created using the templates described in B.2.1 steps 4 and 5 and then imported the data into WDM files as described in B.2.1 step 6.

5. Once time series data for precipitation and other meteorological data were imported into WDM file data sets, additional meteorological time series data were created. This was done using METCMP (computer program for meteorological data generation - HSPF). METCMP enables a user to calculate additional meteorological time series data required by HSPF algorithms, as well as disaggregate daily time series data into hourly time series data for certain meteorological parameters.

- Daily solar radiation for the period 1991-1995 was computed in METCMP using daily cloud cover (DCLO) as an input. The daily solar radiation time series was placed in the DSOL data set. The METCMP disaggregate function then was used to distribute daily solar radiation into hourly values. Hourly solar radiation values were placed in the SOLR data set.

- Daily pan evaporation was computed using the Penman Method in METCMP. Required inputs were: daily maximum (TMAX) and daily minimum (TMIN) temperatures, daily dewpoint temperature (DPTP), daily wind movement (DWND), and daily solar radiation (DSOL). Daily evapotransporation was placed in the DEVP data set. Daily evaporation was distributed into hourly values using the disaggregate function. Hourly evaporation values were placed in the EVAP data set.

- Daily potential evapotranspiration was computed using the Hamon Method in METCMP. Required inputs were: daily maximum (TMAX) and daily (TMIN) temperatures. Daily evapotranspirationwas placed in the DEVT data set. Daily potential evapotranspiration was distributed into hourly values using the disaggregate function. Hourly potential evapotranspiration values were placed in the PEVT data set.

B.2.2.a Coverages Used in BASINS WDM Files Development

- A coverage of cooperative network stations from NCDC's Hourly and Fifteen Minute Precipitation database data set created using latitude and longitude coordinates. The information in this coverage includes:

Station ID#	a cooperative network index number between 1-9999.
State	the state's 2 digit postal code.
Station name	NCDC's assigned station name.
Begin date	first month, day, and year of the period of record.
End date	last month, day, and year of the period of record.

Elevation	meters above sea level (this was converted to feet).
Latitude	in degrees and minutes (always North) (this was converted to decimal degrees).
Longitude	in degrees and minutes (always west) (this was converted to decimal degrees).
Recorded years	the number of years with recorded data (there may be gaps).
Percent coverage	percent of the days between begin and end dates that have reported data.
Precipitation data	a column denoting the database containing the hourly precipitation data.
Relate column	an empty column reserved for the ID# of the NOAA weather station containing meteorological data that will be assigned to the station.

- A coverage of National Weather Service stations from NOAA's Solar and Meteorological Surface Observation Network (SAMSON) data set created using latitude and longitude coordinates. The information included in this coverage included:

Station ID#	the stations Weather Bureau Army Navy number.
State	the state's 2 digit postal code.
Station name	NCDC's assigned station name.
Timezone	lagged by universal time.
Elevation	meters above sea level (this was converted to feet).
Latitude	in degrees and minutes (always North) (this was converted to decimal degrees).
Longitude	in degrees and minutes (always west) (this was converted to decimal degrees).
Evap data	a column denoting the database containing the hourly evaporation data.
Temp data	a column denoting the database containing the hourly temperature data.

Wind data	a column denoting the database containing the hourly windspeed data.
Solar data	a column denoting the database containing the hourly solar radiation data.
Pevt data	a column denoting the database containing the hourly potential evapotranspiration data.
Dew pt data	a column denoting the database containing the hourly dew point temperature data.
Cloud data	a column denoting the database containing the hourly cloud cover data.

- A coverage of the U.S. state boundaries provided by ESRI on-line ArcData (www.esri.com).

- A coverage of annual precipitation for North America provided by ESRI on-line ArcData (www.esri.com). This data set was intended as a thematic data layer representing average annual precipitation, in millimeters per year, for North America

- A coverage of Climate Divisions provided by the National Climatic Data Center (NCDC). This coverage was used to display seasonal maps of precipitation and temperature for the conterminous United States.

- A coverage of Hydrologic Unit Boundaries and Codes provided by the National Climatic Data Center (NCDC). This data set was used to display drainage basins for the conterminous United States.

- A coverage of Physiographic Divisions in the conterminous United States provided by the National Climatic Data Center (NCDC). It was automated from Fennemans 1:7,000,000-scale map, "Physical Divisions of the United States," which is based on eight major divisions, 25 provinces, and 86 sections representing distinctive areas having common topography, rock types and structure, and geologic and geomorphic history.

- A coverage of average annual runoff in the conterminous United States, 1951-1980 provided by the National Climatic Data Center (NCDC). This coverage is intended as a thematic data layer representing average annual runoff, in inches per year, for the conterminous United States. Appropriate maps of the data can show the geographical distribution of runoff in tributary streams for the years 1951-80 and can describe the magnitudes and variations of runoff nationwide. The data was prepared to reflect the runoff of tributary streams rather than in major rivers in order to represent more accurately the local or small scale variation in runoff with precipitation and other geographical characteristics.

APPENDIX B. WEATHER DATA WDM FILE PREPARATION

Summary

A watershed data management (WDM) file was created to input required weather data into the Thumb Run HSPF watershed model. The file was created using the software WDMUtil (Hummel et al., 2001) and data from the Dulles Airport weather station (Co-op ID # 448903) obtained from the National Climatic Data Center (NCDC). Hourly surface data (precipitation, temperature, cloud cover, wind speed, and dew point temperature) was only available from this station after July 1996. Therefore, the WDM was created for the time period July 1, 1996 through September 30, 2001 (end of water quality monitoring period). Weather data from this station was used exclusively to prepare this file, with the exception of volunteer rainfall data that was used to supplement the precipitation data during the period May 2000 through September 2001. Required weather data that was not available from the Dulles station was calculated using functions within WDMUtil.

Data Processing

The WDM file was created for the following parameters:

1. hourly precipitation (PREC) [in],
2. hourly pan evaporation (EVAP) [in],
3. hourly temperature (ATEM) [°F],
4. hourly wind speed (WIND),
5. hourly solar radiation (SOLR) [ly/hr],
6. hourly potential evapotranspiration (PEVT) [in],
7. hourly dew point temperature [°F],
8. hourly cloud cover (CLOU) [none],
9. daily dew point temperature (DPTP) [°F],
10. daily max temperature (TMAX) [°F],
11. daily minimum temperature (TMIN) [°F],
12. daily wind speed (DWND) [mph],
13. daily cloud cover (DCLO) [none],
14. daily solar radiation (DSOL) [ly/day]
15. daily potential evapotranspiration (DEVT) [in]
16. daily pan evaporation (DEVP) [in]

Hourly and daily data purchased from NCDC was in ASCII comma delimited format. The data was formatted to the WDMUtil export format using Microsoft Excel and a text editor (Notepad) and input as a new datasets into the WDM with WDMUtil. Data that was not available from the weather station was calculated in WDMUtil. Missing data was assigned appropriate values according to the BASINS WDM processing methods (see Appendix A). Table B.1 summarizes the parameters that are required in HSPF and what inputs and methods were used to process the parameters. When data was available from NCDC, no further processing in WDMUtil was required.

Table B.1 HSPF required weather parameters and WDMUtil processing.

HSPF Parameter	Input Parameters Required	WDMUtil functions
PREC	PREC	No further processing required
EVAP	TMIN, TMAX, DPTP, DWND, DSOL, DEVP[1]	DISAGGREGATE[2]
ATEM	ATEM	No further processing required
WIND	WIND	No further processing required
SOLR	DSOL[3]	DISAGGREGATE
PEVT	TMAX, TMIN, DEVT[4]	DISAGGREGATE
DEWP	DEWP	No further processing required
CLOU	CLOU	No further processing required

[1] DEVP was computed using the Penman PAN evaopration function in WDMUtil which requires TMIN, TMAX and DPTP, DWND, and DSOL as input.
[2] EVAP was disaggregated from DEVP with the DISAGGREGATE function for DEVT.
[3] DSOL was computed in WDMUtil using the Hamon et al., 1954 equations in WDMUtil.
[4] DEVT was computed using the Hamon PET function in WDMUtil which requires TMIN, TMAX and latitude as input.

APPENDIX C. SELECTED HSPF PARAMETERS FOR THUMB RUN WATERSHED MODEL

Temperature and Snow Parameters

Name	Definition	Units	Range of values				Selected Value
			Typical		Possible		
			Min	Max	Min	Max	
ATEMP - DAT							
ELDAT	Weather station/ watershed elevation diff.	feet	-1000	1000	none	none	190.83
AIRTMP	Initial air temperature	deg. F	30.0	70.0	0.0	90.0	60
SNOW-PARM1							
LAT	Latitude of watershed segment	degrees	30.0	50.0	-90.0	90.0	38.21
MELEV	Mean elevation of watershed segment	feet	50.0	3000.0	0.0	7000.0	712.83
SHADE	Fraction shaded from solar radiation	none	0.1	0.5	0.0	0.8	0.5
SNOWCF	Snow gage catch correction factor	none	1.1	1.5	1.0	2.0	1.2
COVID	Snowfall required to fully cover surface	inches	1.0	3.0	0.1	10.0	2
SNOW-PARM2							
RDCSN	Density of new snow	none	0.10	0.20	0.05	0.30	0.15
TSNOW	Temperature at witch precip becomes snow	deg. F	31.0	33.0	30.0	40.0	32
SNOEVP	Snow evaporation factor	none	0.10	0.15	0.00	0.50	0.1
CCFACT	Condensation/convection melt factor	none	1.0	2.0	0.5	8.0	1
MWATER	Liquid water storage capacity in snowpack	in/in	0.01	0.05	0.005	0.2	0.03
MCMELT	Ground heat daily melt rate	in/day	0.01	0.03	0.0	0.1	0.01

PERLND Module

Pervious Hydrology Parameters - PWAT

Name	Definition	Units	Range of values				Selected Value
			Typical		Possible		
			Min	Max	Min	Max	
PWAT-PARM2							
FOREST	Fraction forest cover	none	0.0	0.50	0.0	0.95	0-0.5
LZSN	Lower Zone Nominal Soil Moisture Storage	inches	3.0	8.0	2.0	15.0	2.8
INFILT	Index to Infiltration Capacity	in/hr	0.01	0.25	0.001	0.50	0.22
LSUR	Length of overland flow	feet	200	500	100	700	300.0
SLSUR	Slope of overland flow plane	ft/ft	0.01	0.15	0.001	0.30	0.0084
KVARY	Variable groundwaterrecession	1/inches	0.0	3.0	0.0	5.0	0.0
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	0.94
PWAT-PARM3							
PETMAX	Temp below which ET is reduced	deg. F	35.0	45.0	32.0	48.0	40.0
PETMIN	Temp below which ET is set to zero	deg. F	30.0	35.0	30.0	40.0	35.0
INFEXP	Exponent in infiltration equation	none	2.0	2.0	1.0	3.0	2.0
INFILD	Ratio of max/mean infiltration capacities	none	2.0	2.0	1.0	3.0	2.0
DEEPFR	Fraction of GW inflow to deep recharge	none	0.0	0.20	0.0	0.50	0.3
BASETP	Fraction of remaining ET from baseflow	none	0.0	0.05	0.0	0.20	0.035
AGWETP	Fraction of remaining ET from active GW	none	0.0	0.05	0.0	0.20	0.0
PWAT-PARM4							
CEPSC	Interception storage capacity	inches	0.03	0.20	0.01	0.40	0.06-0.16
UZSN	Upper zone nominal soil moisture storage	inches	0.10	1.0	0.05	2.0	0.18
NSUR	Manning's n (roughness) for overland flow	none	0.15	0.35	0.05	0.50	0.2-0.35
INTFW	Interflow inflow parameter	none	1.0	3.0	1.0	10.0	1.0

IRC	Interflow recession parameter	none	0.5	0.7	0.3	0.85	0.3
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	0.1-0.7

Pervious Water Quality Parameters - PQUAL

Name	Definition	Units	Range of values				Selected Value
			Typical		Possible		
			Min	Max	Min	Max	
QUAL-INPUT							
ACQOP (MON-ACCUM)	Rate of accumulation of constituent	#/acre*day					3E+6 – 9E+9
SQOLIM	Maximum accumulation of constituent	#/acre					9*ACQOP
WSQOP	Wash-off rate to remove 90 percent of constituent	in/hr					0.6
IOQC	Constituent concentration in interflow	$\#/ft^3$					1416
AOQC	Constituent concentration in Active groundwater	$\#/ft^3$					283.2

IMPLND Module

Impervious Hydrology Parameters - IWAT

Name	Definition	Units	Range of values				Selected Value
			Typical		Possible		
			Min	Max	Min	Max	
IWAT-PARM2							
LSUR	Length of overland flow	feet	50.0	150.0	50.0	250	100.0
SLSUR	Slope of overland flow plane	ft/ft	0.01	0.05	0.001	0.15	0.01
NSUR	Manning's n (roughness) for overland flow	none	0.03	0.10	0.01	0.15	0.1
RETSC	Retention storage capacity	inches	0.03	0.10	0.01	0.30	0.065
IWAT-PARM3							
PETMAX	Temp below which ET is reduced by half	deg. F	35.0	45.0	32.0	48.0	40.0
PETMIN	Temp below which ET is set to zero	deg. F	30.0	35.0	30.0	40.0	35.0

Impervious Water Quality Parameters - IQUAL

Name	Definition	Units	Range of values				Selected Value
			Typical		Possible		
			Min	Max	Min	Max	
QUAL-INPUT							
ACQOP	Rate of accumulation of constituent	#/acre *day					3E+6
SQOLIM	Maximum accumulation of constituent	#/acre					1.6-1.8* ACQOP
WSQOP	Wash-off rate to remove 90 percent of constituent	in/hr					0.6

RCHRES Module

Hydraulic Parameters – HYDR and ADCALC

Name	Definition	Units	Range of values				Selected Value
			Typical		Possible		
			Min	Max	Min	Max	
HYDR-PARM2							
FTBDSN	WDM data set number for FTABLE	none	none	none	1	999	0.0
FTABNO	FTABLE number in UCI file	none	none	none	1	999	1.0
LEN	Stream reach (RCHRES) length	miles	0.1	1.0	0.01	100	9.18
DELTH	Stream reach length change in elevation	feet	10	100	0.1	1000	407.0
STCOR	Stage correction factor	feet	0.0	none	0.0	none	3.2
KS	Routing weighting factor	none	0.0	0.5	0.0	0.99	0.5
DB50	Bed sediment factor	inches	0.01	0.02	0.001	1.00	0.01
ADCALC-DATA							
CRRAT	Ratio of maximum to mean flow velocity	none	1.5	2.0	1.0	3.5	1.5
VOL	Initial stream channel water volume	acre-feet	0.0	none	0.0	none	100.0

In-Stream Water Quality Parameters - GQUAL

Name	Definition	Units	Range of values				Selected Value
			Typical		Possible		
			Min	Max	Min	Max	
GEN-DECAY							
FSTDEC	First order decay rate of the constituent	none	none	none			1.15
THFST	Temperature correction coefficient for FSTDEC	none	none	none			1.05

Note - The definitions of HSPF hydrologic parameters and the range of typical and possible values are taken from the "BASINS Technical Note 6, Estimating Hydrology and Hydraulic Parameters for HSPF" (EPA, 2000).

APPENDIX D. BST FINAL REPORT PRESENTED TO THE RAPPAHANNOCK-RAPIDAN REGIONAL COMMISSION

Use of Antibiotic Resistance Analysis (ARA) to Identify Nonpoint Sources of Fecal Contamination in the Thumb Run Watershed

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The antibiotic resistance analysis (ARA) method of determining the sources of fecal contamination in natural waterways was applied to the Thumb Run watershed. ARA involves isolation of indicator bacteria (enterococci) from different known fecal samples, as well as from unknown water samples. Source identification is accomplished by using the statistical method of discriminant analysis to classify each isolate extracted from water by comparing its antibiotic resistance patterns with the resistance patterns of isolates taken from known fecal samples. The potential sources of fecal contamination in Thumb Run that were tested were beef cattle, horses, humans, geese, and deer and other wild sources. Three water samples were collected at stations along Thumb Run seven times over a 2-month period in the summer of 2001. The samples were processed using ARA, and fecal coliform counts were measured to evaluate the quantity of fecal material in the water. The results indicate that several sources, including cattle, human, geese, and deer contribute to the fecal pollution in Thumb Run. Bacteria from human sources make up the majority of the fecal coliforms found in Thumb Run.

Introduction

Fecal contamination in natural waterways can lead to several problems, including an increased incidence of pathogens (5). Additionally, the increased levels of phosphorous and nitrogen in natural waterways due to fecal pollution can lead to algal blooms that, when degraded, result in deoxygenation of waterways (1). This situation is currently leading to a deterioration of the aquatic environment in the Chesapeake Bay. Fecal contamination in waterways has consistently been demonstrated by the presence of indicator organisms such as fecal coliforms or enterococci (5). However, differentiation of the sources of fecal contamination in waters receiving mixed agricultural and human waste is more difficult. Knowledge of the source of fecal contamination is important because humans are more susceptible to infections by pathogens found in human feces (5). Once the source is identified, steps can be taken to control the influx of fecal pollution.

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Several approaches have been developed for the source identification of fecal contamination. The ratio of fecal coliforms to fecal streptococci, and the presence of certain bacteriophages as source indicators have been used (6). Another method involves DNA “fingerprinting” of fecal coliforms using pulsed field gel electrophoresis (PFGE) analysis to differentiate between the variations in restriction fragments of bacteria that are found in the feces of different hosts (2). Ribotyping uses the slight differences in ribosomal RNA in *E. coli* isolated from the feces of different hosts to identify the source of fecal pollution (2).

Antibiotic resistant bacteria can develop in animals and humans as a result of treatment with antibiotics. Several methods of source identification are based on differences in antibiotic resistance among bacteria from different sources. Krumperman developed multiple antibiotic resistance (MAR) indexing as a method of quantifying the frequency of occurrence of multiple antibiotic resistant *E. coli* in fecal material (4). He was able to demonstrate a difference in MAR indices of *E. coli* isolated from wild sources with those isolated from humans or poultry. Similarly, Kaspar et al. (3) were able to demonstrate a difference in MAR indices from rural and urban sources.

Our laboratory has developed antibiotic resistance analysis (ARA), which uses enterococci as an indicator organism in identification of sources of fecal contamination (6). Enterococci are a group of gram-positive, catalase-negative cocci that hydrolyze esculin, and are capable of growing at 6.5 percent NaCl and at 45°C. Enterococci are used because they survive well in natural waters and can be isolated from all potential sources of fecal pollution (6, 7). In this approach, enterococci are isolated from known fecal sources, and grown on plates containing various concentrations of 11 different antibiotics. The resulting antibiotic resistance patterns of each isolate are then analyzed using discriminant analysis, a multivariate statistical method. The results are pooled to form a "known library" of antibiotic resistance patterns from different fecal sources. Resistance patterns of isolates from natural waterways are then compared with this known library to determine the source(s) of fecal pollution in that waterway (6, 7). In this study, we also have used a new variation of the ARA technique, which uses fecal coliforms instead of enterococci as the test organism.

In this report, ARA and fecal coliform counts were used to draw conclusions about the source(s) of fecal contamination in the Thumb Run watershed. Thumb Run is located in Fauquier County, Virginia, and is highly polluted with fecal matter . Thumb Run feeds the Rappahannock River and flows eventually into the Chesapeake Bay. The possible sources of fecal contamination in the Thumb Run watershed have been identified as beef cattle, failing septic systems, horses, geese, and other wild animals. Seven sets of samples were analyzed during the course of two months during the summer of 2001.

Materials and Methods

Sample Collection:

All samples were collected by Jeff Walker and shipped by overnight delivery to the laboratory. All known samples were collected in sterile whirl-pack bags. The numbers and sources of the samples are shown in Table 1. Three sites were sampled along Thumb Run during each sampling event (Table 2). Stream (unknown) samples were collected on 7/24, 8/3, 8/15, 8/21, 9/6, 9/12, and 9/26. A total of 21 stream samples were collected. Unknown samples were collected in sterile containers. The goal was to test 46 isolates from each sample, resulting in a precision of approximately 2 percent. Because of low counts, fewer isolates were analyzed for some samples.

Table D.1. Numbers of known fecal samples and isolates used in this study, and averages of the numbers of indicator organisms in each source.

Source	# of Samples	# of Isolates	Ave. # FC	Ave. # ENT
Beef Cattle	8	63	1.2E+05/g	1.6E+05/g
Horses	9	79	1.3E+06/g	2.4E+06/g
Septic tank samples	11	109	1.3E+04/ml	2.3E+03/ml
Geese	7	63	7.6E+06/g	4.9E+06/g
Small Carnivore	5	38	6.9E+06/g	9.3E+06/g
Deer	8	72	1.0E+07/g	2.5E+06/g
Totals	48	424	--	--

Table D.2. Location and description of sampling sites in the Thumb Run watershed.

Site	Latitude / Longitude	Description
1	38.77 / 77.98	Main Stem of Thumb Run
2	38.79 / 77.97	West Branch
3	38.30 / 77.96	East Branch

Isolation of enterococci:

Varying amounts of fecal samples (0.1 – 0.5 g) were suspended in 50 ml of saline buffer. The sample was mixed vigorously before filtering through 0.45-µm pore-size filters. Varying volumes of unknown water samples were filtered using the same filters. The filters were placed in 50 mm petri dishes containing 5 ml of m-Enterococcus agar. The petri dishes were incubated at 37°C for 48 hours. After incubation, isolated colonies were selected (48 for unknown samples, and 12-24 for known samples) and transferred to 96-microwell plates containing 0.2 ml of Enterococcosel broth. The microwell plates were incubated at 37°C for 48 hours. Esculin-negative isolates were not analyzed.

Enteroccocci (ENT) counts were performed by filtering various volumes of all unknown stream samples, and of the suspended fecal samples (as described above). The filters were then placed in 50 mm petri-dishes containing 5 ml of m-Enterococcus agar. The petri dishes were incubated at 37°C for 48 hours. After incubation, the number of red colonies were enumerated and recorded. In the tables, the values in the "average" rows are geometric means.

Isolation of Fecal Coliforms:

Varying amounts of fecal samples (0.1 – 0.5 g) were suspended in 50 ml of saline buffer. The sample was mixed vigorously before filtering through 0.45-µm pore-size filters. Varying volumes of unknown water samples were filtered using the same filters. The filters were placed in 50 mm petri dishes containing 5 ml of m-FC agar. The petri dishes were incubated at 44.5°C for 24 hours. After incubation, isolated colonies were selected (48 for unknown samples, and 12-24 for known samples) and transferred to 96-microwell plates containing 0.2 ml of Colilert broth. The microwell plates were incubated at 37°C for 24 hours. MUG-negative isolates were not analyzed.

Fecal coliform (FC) counts were performed by filtering various volumes of all unknown stream samples, and of the suspended fecal samples (as described above). The filters were then placed in 50 mm petri-dishes containing 5 ml of m-FC agar. The petri dishes were incubated in a water bath at 44.5°C for 18 – 24 hours. After incubation, the number of blue colonies were enumerated and recorded. In the tables, the values in the "average" rows are geometric means.

Antibiotics:

Isolates from the 96-microwell plate were transferred to antibiotic-containing Trypticase Soy agar (TSA) plates using a sterile 48-prong replica-plater. For enterococci, various concentrations of 11 antibiotics were used (37 concentrations total) (8). For fecal coliforms, various concentrations of 6 antibiotics were used (25 concentrations total). The isolates were also replica-plated to two TSA plates that did not contain antibiotics as a control. All TSA plates were incubated at 37°C for 24-48 hours. After incubation, the growth of each isolate on each concentration of each antibiotic was determined, and the resulting antibiotic resistance patterns were combined to form a library of known sources.

Statistical Analysis:

The results from resistance testing were entered into the SAS statistical program where they were analyzed using the DISCRIM procedure, which produces a classification table. The average rate of correct classification (ARCC) is the average rate that known isolates are correctly classified, and was used to measure the reliability of the known library. The Minimum Detectable Percentage (MDP) for each source type was determined by averaging the percentages of other source types that were misclassified as that type. This value is the minimum percentage for each particular source that can be detected in a stream sample.

Results

Two types of source tracking methods were performed for this watershed. We used our regular method, using the enteroccocci, and a new method using fecal coliforms. Both types of bacteria were isolated from the known fecal samples and from the stream samples, and separate libraries were created for each.

Two-way Classification of Isolates: Human vs. Animal

To determine if the pollution in Thumb Run was from humans or animals, libraries were created where all animal sources were pooled together. The average rate of correct classification (ARCC) of the ENT library was 90 percent, which was well above the background level of 50 percent, and the Minimum Detectable Percentage (MDP) was 17 percent for animals and 3 percent for humans (Table 3). The FC library was not as successful at classifying the sources.

For this library, the average rate of correct classification (ARCC) was 73 percent, which was also well above the background level of 50 percent, and the Minimum Detectable Percentage (MDP) was 28 percent for animals and 27 percent for humans (Table 4).

Table D.3. Classification of 467 isolates of enterococci from known animal and human sources in the Thumb Run watershed.

Correctly-classified isolates are shown in **bold**. The ARCC for this analysis is 90 percent.

	Number (and Percent) of Isolates Classified As:	
SOURCE	ANIMAL	HUMAN
ANIMAL (n = 349)	**339 (97)**	10 (3)
HUMAN (n = 118)	20 (17)	**98 (83)**
MDP	17	3

Table D.4. Classification of 424 isolates of fecal coliforms from known animal and human sources in the Thumb Run watershed.

Correctly-classified isolates are shown in **bold**. The ARCC for this analysis is 73 percent.

	Number (and Percent) of Isolates Classified As:	
SOURCE	ANIMAL	HUMAN
ANIMAL (n = 315)	**229 (73)**	86 (27)
HUMAN (n = 109)	30 (28)	**79 (72)**
MDP	28	27

Using these libraries, the 21 stream samples were classified. The results are shown in Tables 5 and 6 (listed by collection date) and 7 and 8 (listed by sample site). Both human and animal sources were identified in the stream. There was variation from station to station, and from day to day, but some clear trends are evident:

1. On average, all stations are polluted by animals. Based on the ENT library, animal sources were the major source on all seven sampling days, and at all three stations. Animal sources were above the MDP and were the major source in all 21 samples. The FC library also showed that animal sources were dominant (it was the major source in 14 of 21 samples). In both libraries, animal sources were present at levels above the MDP for the vast majority of samples.

2. Human pollution is present as well. The MDP for humans in the ENT library is 3 percent. This means that if human pollution is present at more than 3 percent in a given sample, it is unlikely to be a result of misclassification of the animal sources. Based on the ENT library, there were 9 of the 21 samples with human values greater than 3 percent. The FC library has a higher MDP for human sources (27 percent) as a result of its reduced classification success rate. But

even so, 17 of the 21 samples showed human values that were above the MDP, and 8 samples showed human as the major source.

3. The two libraries differ with respect to the proportions of sources over the course of the 2-month sampling period. The ENT library showed that the proportions were reasonably consistent, with the exception of the final sampling date. On this day the numbers of indicator organisms in the water increased dramatically, and the proportion of human sources also increased. While the FC library also showed a high proportion of human sources on that day, there were other days with similarly high values.

Table D.5. Two-way classification of enteroccocci from known fecal sources in Thumb Run, listed by collection date.

Values in *italics* are the major source. Values in **bold** are above the MDP.

A. Samples collected on 7/24/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	45	*76*	**24**	40	81
2	46	*83*	**17**	73	55
3	24	*100*	0	175	21
Average		*86*	**14**	80	45

B. Samples collected on 8/3/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	44	*98*	2	150	96
2	34	*100*	0	190	87
3	44	*95*	**5**	905	570
Average		*98*	2	295	168

C. Samples collected on 8/15/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	42	*95*	**5**	405	280
2	42	*95*	**5**	495	360
3	34	*100*	0	270	510
Average		*97*	3	378	372

D. Samples collected on 8/21/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	44	*93*	**7**	95	170
2	42	*98*	2	120	265
3	41	*100*	0	125	465
Average		*97*	3	113	276

E. Samples collected on 9/6/01

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	41	*100*	0	37	160
2	44	*80*	**20**	102	375
3	42	*98*	2	86	28
Average		*93*	**7**	69	119

F. Samples collected on 9/12/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	36	*100*	0	79	185
2	44	*100*	0	220	645
3	44	*100*	0	655	465
Average		*100*	0	225	381

G. Samples collected on 9/26/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	44	*80*	**20**	2500	41000
2	46	*89*	**11**	14350	50000
3	45	*87*	**13**	7567	23000
Average		*85*	**15**	6475	36127

Table D.6. Two-way classification of E. coli from known fecal sources in Thumb Run, listed by collection date.

Values in *italics* are the major source. Values in **bold** are above the MDP.

A. Samples collected on 7/24/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	44	*68*	**32**	40	81
2	41	*66*	**34**	73	55
3	25	4	*96*	175	21
Average		46	*54*	80	45

B. Samples collected on 8/3/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	42	*64*	**36**	150	96
2	45	*73*	**27**	190	87
3	45	*60*	**40**	905	570
Average		*66*	**34**	295	168

C. Samples collected on 8/15/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	43	9	***91***	405	280
2	44	**41**	*59*	495	360
3	34	21	*79*	270	510
Average		24	*76*	378	372

D. Samples collected on 8/21/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	43	*63*	**37**	95	170
2	44	*82*	18	120	265
3	29	*97*	3	125	465
Average		*81*	19	113	276

E. Samples collected on 9/6/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	41	**32**	*68*	37	160
2	42	*50*	*50*	102	375
3	43	*86*	14	86	28
Average		*56*	**44**	69	119

F. Samples collected on 9/12/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	41	*80*	20	79	185
2	40	*62*	**38**	220	645
3	28	*54*	**46**	655	465
Average		*65*	**35**	225	381

G. Samples collected on 9/26/01.

Site #	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	#ENT/100ml
1	37	**35**	*65*	2500	41000
2	43	*56*	**44**	14350	50000
3	42	**43**	*57*	7567	23000
Average		**45**	*55*	6475	36127

Table D.7. Two-way classification of enterococci from known fecal sources in Thumb Run, listed by sample site.

Values in *italics* are the major source. Values in **bold** are above the MDP.

A. Samples collected at site 1.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	# ENT/100ml
7/24/2001	45	*76*	**24**	40	81
8/3/2001	44	*98*	2	150	96
8/15/2001	42	*95*	**5**	405	280
8/21/2001	44	*93*	7	95	170
9/6/2001	41	*100*	0	37	160
9/12/2001	36	*100*	0	79	185
9/26/2001	44	*80*	**20**	2500	41000
Average		*92*	**8**	150	332

B. Samples collected at site 2.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	# ENT/100ml
7/24/2001	46	*83*	**17**	73	55
8/3/2001	34	*100*	0	190	87
8/15/2001	42	*95*	**5**	495	360
8/21/2001	42	*98*	2	120	265
9/6/2001	44	*80*	**20**	102	375
9/12/2001	44	*100*	0	220	645
9/26/2001	46	*89*	**11**	14350	50000
Average		*92*	**8**	308	476

C. Samples collected at site 3.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	# ENT/100ml
7/24/2001	24	*100*	0	175	21
8/3/2001	44	*95*	**5**	905	570
8/15/2001	34	*100*	0	270	510
8/21/2001	41	*100*	0	125	465
9/6/2001	42	*98*	2	86	28
9/12/2001	44	*100*	0	655	465
9/26/2001	45	*87*	**13**	7567	23000
Average		*97*	3	419	364

Table D.8. Two-way classification of E. coli from known fecal sources in Thumb Run, listed by sample site.

Values in *italics* are the major source. Values in **bold** are above the MDP.

A. Samples collected at site 1.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	# ENT/100ml
7/24/2001	44	*68*	**32**	40	81
8/3/2001	42	*64*	**36**	150	96
8/15/2001	43	9	*91*	405	280
8/21/2001	43	*63*	**37**	95	170
9/6/2001	41	**32**	*68*	37	160
9/12/2001	41	*80*	20	79	185
9/26/2001	37	**35**	*65*	2500	41000
Average		*50*	*50*	150	332

B. Samples collected at site 2.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	# ENT/100ml
7/24/2001	41	*66*	**34**	73	55
8/3/2001	45	*73*	**27**	190	87
8/15/2001	44	**41**	*59*	495	360
8/21/2001	44	*82*	18	120	265
9/6/2001	42	*50*	*50*	102	375
9/12/2001	40	*62*	**38**	220	645
9/26/2001	43	*56*	**44**	14350	50000
Average		*61*	**39**	308	476

C. Samples collected at site 3.

Date	# of isolates	%ANIMAL	%HUMAN	# FC/100ml	# ENT/100ml
7/24/2001	25	4	*96*	175	21
8/3/2001	45	*60*	**40**	905	570
8/15/2001	34	21	**79**	270	510
8/21/2001	29	*97*	3	125	465
9/6/2001	43	*86*	14	86	28
9/12/2001	28	*54*	**46**	655	465
9/26/2001	42	**43**	*57*	7567	23000
Average		*52*	**48**	419	364

Five-way Classification of Isolates: Cattle vs. Goose vs. Horse vs. Human vs. Wild

To determine which animal sources are contributing to the pollution in Thumb Run, five-way libraries were created. Deer and small carnivore samples were pooled together as "wild". The ARCC of the ENT library was 67 percent, which was well above the background level of 20 percent (Table 9). The MDP for human was the lowest (2 percent), and the rest were around 10 percent Again, the FC library was not as good at classifying the isolates. The ARCC for the FC library was 49 percent, with MDPs ranging from 10 percent to 19 percent (Table 10).

Table D.9. Classification of 467 isolates of enterococci from known cattle, goose, horse, human, and wild sources in the Thumb Run watershed.

Correctly-classified isolates are shown in **bold**. The ARCC for this analysis is 67 percent.

	Number (and Percent) of Isolates Classified As:				
SOURCE	**CATTLE**	**GOOSE**	**HORSE**	**HUMAN**	**WILD**
CATTLE (n = 67)	**51 (76)**	5 (8)	4 (6)	2 (3)	5 (7)
GOOSE (n = 70)	3 (4)	**46 (66)**	9 (13)	2 (3)	10 (14)
HORSE (n=87)	15 (17)	16 (19)	**46 (53)**	1 (1)	9 (10)
HUMAN (n=118)	5 (4)	3 (3)	5 (4)	**94 (80)**	11 (9)
WILD (n=125)	18 (14)	21 (17)	11 (9)	0 (0)	**75 (60)**
MDP	10	11	8	2	10

Table D.10. Classification of 424 isolates of fecal coliforms from known cattle, goose, horse, human, and wild sources in the Thumb Run watershed.

Correctly-classified isolates are shown in **bold**. The ARCC for this analysis is 49 percent.

	Number (and Percent) of Isolates Classified As:				
SOURCE	**CATTLE**	**GOOSE**	**HORSE**	**HUMAN**	**WILD**
CATTLE (n = 63)	**31 (49)**	9 (14)	7 (11)	11 (18)	5 (8)
GOOSE (n = 63)	3 (5)	**28 (44)**	12 (19)	14 (22)	6 (10)
HORSE (n=79)	13 (16)	10 (13)	**31 (39)**	18 (23)	7 (9)
HUMAN (n=109)	4 (4)	19 (17)	7 (6)	**65 (60)**	14 (13)
WILD (n=110)	15 (14)	10 (9)	9 (8)	17 (15)	**59 (54)**
MDP	10	13	11	19	10

Using these libraries, the stream samples were classified. The results are shown in Tables 11 and 12 (listed by collection date) and 13 and 14 (listed by sample site). All five source types were found in Thumb Run. Again, there was variation from station to station and from day to day, and again, some clear trends are evident:

1. Cattle and wild sources (including deer) were major sources in most samples, based on both the ENT and FC libraries. With the ENT library, cattle sources were detected at levels above the MDP in 18 of 21 samples, and wild sources at levels above the MDP were detected in all 21 samples. Using the FC library, cattle sources were above the MDP in 14 samples and wild sources were above the MDP in 11 samples.

2. Human sources were found in just 8 samples using the ENT library, and none of them had human as the major source. However, using the FC library, human sources were found in 13 samples, and human was the major source in 10 of them.

3. Goose sources were detected in several samples. Using the ENT library, 10 of 21 samples had levels above the MDP, and goose was the major source in 2 samples. The FC library also showed 10 samples with goose source levels above the MDP, and 4 samples had goose as the major source. Goose sources were more frequently detected at station 2.

4. Horse sources were also detected in several samples. Using the ENT library, 10 of 21 samples had levels above the MDP, but none of them had horse as the major source. The FC library also showed 9 samples with horse source levels above the MDP, and 1 sample had horse as the major source.

5. Similar to the two-way classification, the ENT library showed that there were higher levels of human sources on 9/26/01. The FC library showed high human levels on this date, and on 8/15/01 as well.

Table D.11. Five-way classification of enteroccocci from known fecal sources in Thumb Run. Listed values in *italics* are the major source. Values in **bold** are above the MDP.by collection date. Values in *italics* are the major source. Values in **bold** are above the MDP.

A. Samples collected on 7/24/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	45	*42*	5	**13**	**7**	**33**	40	81
2	46	*41*	**20**	**9**	**6**	**24**	73	55
3	24	*42*	**17**	4	0	**37**	175	21
Average		*42*	**14**	**9**	**4**	**31**	80	45

B. Samples collected on 8/3/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	44	*41*	2	**14**	0	**43**	150	96
2	34	3	9	**12**	0	*76*	190	87
3	44	*57*	9	**16**	2	**16**	905	570
Average		**34**	7	**14**	1	*45*	295	168

C. Samples collected on 8/15/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	42	*52*	2	3	**3**	**40**	405	280
2	42	**21**	**17**	0	2	*60*	495	360
3	34	*44*	9	3	0	*44*	270	510
Average		**39**	9	2	2	*48*	378	372

D. Samples collected on 8/21/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml

1	44	7	4	**18**	**7**	*64*	95	170
2	42	5	**26**	**10**	0	*59*	120	265
3	41	**24**	3	**22**	0	*51*	125	465
Average		**12**	11	**17**	2	*58*	113	276

E. Samples collected on 9/6/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	41	**39**	5	2	0	*54*	37	160
2	44	**11**	**16**	0	**12**	*61*	102	375
3	42	**35**	5	5	0	*55*	86	28
Average		**28**	9	2	**4**	*57*	69	119

F. Samples collected on 9/12/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	36	**14**	**14**	3	0	*69*	79	185
2	44	2	*59*	0	0	**39**	220	645
3	44	**25**	**25**	2	0	*48*	655	465
Average		**14**	**33**	2	0	*52*	225	381

G. Samples collected on 9/26/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	44	**36**	7	2	**14**	*41*	2500	41000
2	46	*37*	**20**	**11**	**6**	**26**	14350	50000
3	45	**20**	*36*	**9**	**11**	**24**	7567	23000
Average		*31*	**21**	7	**10**	**30**	6475	36127

Table D.12. Five-way classification of E. coli from known fecal sources in Thumb Run, listed by collection date.

Values in *italics* are the major source. Values in bold are above the MDP.

A. Samples collected on 7/24/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	44	*30*	7	**18**	16	**29**	40	81
2	41	**27**	*39*	10	14	**10**	73	55
3	25	8	0	0	*92*	0	175	21
Average		**22**	**15**	9	*41*	**13**	80	45

B. Samples collected on 8/3/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	42	*26*	**24**	**12**	*26*	**12**	150	96
2	45	**11**	*44*	**22**	16	7	190	87
3	45	**13**	**18**	*25*	**22**	**22**	905	570
Average		**17**	*29*	**20**	**21**	**14**	295	168

C. Samples collected on 8/15/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	43	0	**14**	2	*72*	**12**	405	280
2	44	**25**	**16**	9	*41*	9	495	360
3	34	9	3	6	*73*	9	270	510
Average		**11**	11	6	*62*	**10**	378	372

D. Samples collected on 8/21/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	43	*35*	12	2	**28**	**23**	95	170
2	44	*48*	**14**	**20**	4	**14**	120	265
3	29	**17**	0	7	4	*72*	125	465
Average		**33**	9	10	12	*36*	113	276

E. Samples collected on 9/6/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	41	0	12	7	*66*	**15**	37	160
2	42	7	3	0	**33**	*57*	102	375
3	43	**33**	0	7	7	*53*	86	28
Average		**13**	5	5	**35**	*42*	69	119

F. Samples collected on 9/12/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	41	**17**	*37*	**27**	12	7	79	185
2	40	8	**32**	5	*55*	0	220	645
3	28	0	*86*	3	11	0	655	465
Average		8	*52*	**12**	**26**	2	225	381

G. Samples collected on 9/26/01.

Site #	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	#ENT/100ml
1	37	**11**	3	**27**	*51*	8	2500	41000
2	43	**31**	9	**16**	*37*	7	14350	50000
3	42	**14**	12	**19**	*53*	2	7567	23000
Average		**19**	8	**21**	*47*	6	6475	36127

Table D.13. Five-way classification of enterococci from known fecal sources in Thumb Run, listed by sample site.

Values in *italics* are the major source. Values in **bold** are above the MDP.

A. Samples collected at site 1.

Date	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	# ENT/100ml
7/24/2001	45	*42*	5	**13**	**7**	**33**	40	81
8/3/2001	44	*41*	2	**14**	0	**43**	150	96
8/15/2001	42	*52*	2	3	**3**	**40**	405	280
8/21/2001	44	7	4	**18**	**7**	*64*	95	170
9/6/2001	41	**39**	5	2	0	*54*	37	160
9/12/2001	36	**14**	**14**	3	0	*69*	79	185
9/26/2001	44	**36**	7	2	**14**	*41*	2500	41000

Average		**33**	6	8	**4**	*49*	150	332

B. Samples collected at site 2.

Date	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	# ENT/100ml
7/24/2001	46	*41*	**20**	**9**	**6**	**24**	73	55
8/3/2001	34	3	9	**12**	0	*76*	190	87
8/15/2001	42	**21**	**17**	0	2	*60*	495	360
8/21/2001	42	5	**26**	**10**	0	*59*	120	265
9/6/2001	44	**11**	**16**	0	**12**	*61*	102	375
9/12/2001	44	2	*59*	0	0	**39**	220	645
9/26/2001	46	*37*	**20**	**11**	**6**	**26**	14350	50000
Average		**17**	**24**	6	**4**	*49*	308	476

C. Samples collected at site 3.

Date	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	# ENT/100ml
7/24/2001	24	*42*	**17**	4	0	**37**	175	21
8/3/2001	44	*57*	9	**16**	2	**16**	905	570
8/15/2001	34	*44*	9	3	0	*44*	270	510
8/21/2001	41	**24**	3	**22**	0	*51*	125	465
9/6/2001	42	**35**	5	5	0	*55*	86	28
9/12/2001	44	**25**	**25**	2	0	*48*	655	465
9/26/2001	45	**20**	*36*	**9**	**11**	**24**	7567	23000
Average		**35**	**15**	**9**	2	*39*	419	364

Table D.14. Five-way classification of E. coli from known fecal sources in Thumb Run, listed by sample site.

Values in *italics* are the major source. Values in **bold** are above the MDP.

A. Samples collected at site 1.

Date	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	# ENT/100ml
7/24/2001	44	*30*	7	**18**	16	**29**	40	81
8/3/2001	42	*26*	**24**	**12**	*26*	**12**	150	96
8/15/2001	43	0	**14**	2	*72*	**12**	405	280
8/21/2001	43	*35*	12	2	**28**	**23**	95	170
9/6/2001	41	0	12	7	*66*	**15**	37	160
9/12/2001	41	**17**	*37*	**27**	12	7	79	185
9/26/2001	37	**11**	3	**27**	*51*	8	2500	41000
Average		**17**	**16**	**14**	*39*	**15**	150	332

B. Samples collected at site 2.

Date	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	# ENT/100ml
7/24/2001	41	**27**	*39*	10	14	**10**	73	55
8/3/2001	45	**11**	*44*	**22**	16	7	190	87
8/15/2001	44	**25**	**16**	9	*41*	9	495	360
8/21/2001	44	***48***	**14**	**20**	4	**14**	120	265

9/6/2001	42	7	3	0	**33**	*57*	102	375
9/12/2001	40	8	**32**	5	*55*	0	220	645
9/26/2001	43	**31**	9	**16**	*37*	7	14350	50000
Average		**22**	**22**	**12**	*29*	**15**	308	476

C. Samples collected at site 3.

Date	# of isolates	%CATTLE	%GOOSE	%HORSE	%HUMAN	%WILD	# FC/100ml	# ENT/100ml
7/24/2001	25	8	0	0	*92*	0	175	21
8/3/2001	45	**13**	**18**	*25*	**22**	**22**	905	570
8/15/2001	34	9	3	6	*73*	9	270	510
8/21/2001	29	**17**	0	7	4	*72*	125	465
9/6/2001	43	**33**	0	7	7	*53*	86	28
9/12/2001	28	0	*86*	3	11	0	655	465
9/26/2001	42	**14**	12	**19**	*53*	2	7567	23000
Average		**13**	**17**	10	*37*	**23**	419	364

Levels of Indicator Organisms

Fecal coliform levels were generally low in most samples. Only 3 samples had FC levels above the standard of 1000 FC/100 ml, and all of these were on the same day (9/26/01). The geometric mean of the FC counts exceeded 200 FC/100 ml at stations 2 and 3. Enterococci counts were similar to FC counts in the water samples.

Fecal coliform and enterococci counts were also measured in the known fecal samples. Counts ranged from 1 x 10^5 to 1 x 10^7 cells/g (Table 1). Generally, levels of FC and ENT were similar in the different source types, with the exception of human septic samples, which had much higher FC than ENT counts. Septic samples had much lower total counts (1 x 10^3 to 1 x 10^4 cells/ml), but this was because the fecal material was diluted in water.

Discussion

These results show that animals are a major sources of pollution in Thumb Run. However, human sources are significant contributors as well. All three sites had average percentages of both animal and human sources that were at or above the minimum detectable level.

Of the animal sources, the dominant source is cattle and wild animals. Tables 15 and 16 show the major source of fecal contamination at each sample site as determined by each library. The ENT library shows cattle was the major source in 8 samples, and wild was the major source in 11 samples. In contrast, the FC library showed that human was the major source in 10 samples, with cattle and wild dominant in just 4 and 3 samples, respectively.

Table D.15. The dominant source (and percent) of fecal contamination found in each sample site during each sampling event, based on the enterococcus library.

C=cattle, **G**=goose, **Hr**=horse, **Hu**=human; **W**=wild.

	Sample Date						
Site	7/24/01	8/3/01	8/15/01	8/21/01	9/6/01	9/12/01	9/26/01
	C (42)	**C** (41)	**C** (52)	**W** (64)	**W** (54)	**W** (69)	**W** (41)
	C (41)	**W** (76)	**W** (60)	**W** (59)	**W** (61)	**G** (59)	**C** (37)
	C (42)	**C** (57)	**C** (44)	**W** (51)	**W** (55)	**W** (48)	**G** (36)

Table D.16. The dominant source (and percent) of fecal contamination found in each sample site during each sampling event, based on the fecal coliform library.

C=cattle, **G**=goose, **Hr**=horse, **Hu**=human; **W**=wild.

	Sample Date						
Site	7/24/01	8/3/01	8/15/01	8/21/01	9/6/01	9/12/01	9/26/01
	C (30)	**C, Hu** (26)	**Hu** (72)	**C** (35)	**Hu** (66)	**G** (37)	**Hu** (51)
	G (39)	**G** (44)	**Hu** (41)	**C** (48)	**W** (57)	**Hu** (55)	**Hu** (37)
	Hu (92)	**Hr** (25)	**Hu** (73)	**W** (72)	**W** (53)	**G** (86)	**Hu** (53)

The two libraries differ in the nature and extent of the sources of fecal pollution in Thumb Run. The ENT library has a strong level of classification success. When the isolates from the known samples were analyzed using our large multi-watershed library, they were classified reasonably well, suggesting that these known are similar to other known sources in Virginia, and, by extension, that the unknown results are valid. However, the ENT method does not test the actual bacteria that are being regulated, the fecal coliforms. That is why we tried the new method and generated the FC library. This library had a lower classification success rate, and, because it is a new method, we have no other libraries to compare it to.

The FC library showed a higher proportion of human sources than did the ENT library. This is not inconsistent with the ENT library, however, if the number of bacteria in the various fecal sources is considered. The septic samples had much higher proportion of FC than enterococci. Therefore, in a water sample that is polluted by human and animal sources, there would be a higher proportion of human FC than human enterococci, and thus the FC library would show a higher proportion of human isolates than would the ENT library. Because the FC library is measuring the proportions of fecal coliforms in the stream, it seems logical to put more weight on this library, even if its level of classification success is lower than the ENT library.

Even with these differences, the libraries are in agreement on most points. Both show the presence of human sources in the stream, and both show that cattle, geese, deer and other wild animals are major contributors. Both show that horses are only minor contributors. And both show that the sources are found at all three sites, with the exception of goose, which seems to be higher at site 2.

Limitations of this study. The water samples analyzed in this study were collected over a two-month period. There may be seasonal variation in the numbers and proportions of sources at other times of the year. Additionally, the number of known samples that were used to comprise the libraries is small. The isolates from the ENT library seem reasonably representative compared to other known samples, but the representativeness of the FC isolates is unknown. Finally, keep in mind that all BST methods, including ARA, are still being developed, and there are no "standard methods" yet for any method. There are many variables that determine the sources of fecal bacteria in water, and many of them are poorly understood.

Conclusions. In conclusion, the levels of FC in Thumb Run were moderate, with very high levels observed on one day. Thumb Run receives fecal pollution from several sources, including cattle, geese, deer and other wild animals, and humans. Bacteria from human sources make up the majority of the fecal coliforms found in Thumb Run.

Acknowledgments

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Sample numbers used in this report

Sample numbers according to type used in these analyses.

Beef: 1548, 1561, 1586, 1608, 1647, 1678, 1679, 1680

Small carnivore: 1581, 1582, 1583, 1638, 1687

Goose: 1526, 1610, 1611, 1643, 1644, 1684, 1685

Horse: 1524, 1560, 1587, 1609, 1645, 1646, 1681, 1682, 1683

Human: 1558, 1559, 1612, 1613, 1614, 1635, 1636, 1637, 1675, 1676, 1677

Deer: 1525, 1584, 1585, 1639, 1640, 1641, 1642, 1686

APPENDIX E. SAMPLE CALCULATION: DISTRIBUTION OF CATTLE IN THE WEST1 SUBWATERSHED

(Note: Due to rounding, some numbers might not add up)

1. Determine the cattle population in West1.

   From Section 3.2.1: there are 300 cattle in the subwatershed.

2. Determine the confinement schedule of cattle in the subwatershed.

   There is no confinement of cattle within the Thumb Run watershed.

3. Multiply the population of cattle by the percent of pasture acreage that has stream access.

   70 percent of pasture acreage has stream access, therefore:

   Cattle on pastures with stream access = 300*(0.7) = 210

4. Multiply the population of cattle on pasture areas with stream access by the amount of time that cattle spend in and around the stream each month.

   In January, cattle spend 1/24 days (Table 3.3) in and around the stream.

   Cattle in and around the stream each day = 210*(1/24 days) = 9

5. Multiply the population of cattle in and around the stream each day by 30 percent to determine the number of cattle defecating directly in the stream each day.

   Cattle defecting in the stream each day = 9*(0.3) = 3

6. Subtract the population of cattle defecating directly in the stream from the total population of cattle in the subwatershed to determine the number of cattle defecating on pasture each day.

   Cattle defecating on pasture each day = 300 – 3 = 297

7. Determine the population of cattle on each landuse.

   Cattle remain on "pasture 1" and "pasture 2" landuses. The stocking density on "pasture 2" landuse is twice that on "pasture 1" (Section 3.2.1).

The “pasture 1” and “pasture 2” acreage in West1 is 1973.1 acres and 207.5 acres respectively (Table 4.5).

The portion of cattle on “pasture 1” is:

[1973.1 acres / (1973.1 acres + 2*207.5 acres)]*100 = 82.6 percent

Therefore,

Cattle defecating on “pasture 1” landuse = 297*(0.826) = 245

and

Cattle defecating on “pasture 2” landuse = 297 – 245 = 52.

APPENDIX F. DAILY NONPOINT FECAL COLIFORM LOADINGS TO LANDUSE TYPES IN EACH SUBWATERSHED OF THE THUMB RUN WATERSHED

Table F.1. Daily nonpoint fecal coliform loadings to subwatershed West1 per acre of landuse.

Month	Daily Fecal Coliform Loads to Landuse Type/PERLND # (cfu/acre*day)							Total (cfu/ acre*day)
	Forest	Pasture 1	Pasture 2	Farmstead	Rural Res	Cropland	Urban	
	101	102	103	104	105	106	107	
January	4.27E+06	2.59E+09	5.18E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.14E+10
February	4.27E+06	2.59E+09	5.18E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.14E+10
March	4.27E+06	2.58E+09	5.16E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.13E+10
April	4.27E+06	2.57E+09	5.14E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.13E+10
May	4.27E+06	2.57E+09	5.14E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.13E+10
June	4.27E+06	2.56E+09	5.11E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.13E+10
July	4.27E+06	2.56E+09	5.11E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.13E+10
August	4.27E+06	2.56E+09	5.11E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.13E+10
September	4.27E+06	2.57E+09	5.14E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.13E+10
October	4.27E+06	2.58E+09	5.16E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.13E+10
November	4.27E+06	2.58E+09	5.16E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.13E+10
December	4.27E+06	2.59E+09	5.18E+09	1.80E+09	1.80E+09	3.33E+06	0.00E+00	1.14E+10

Table F.2. Daily nonpoint fecal coliform loadings to subwatershed West2 per acre of landuse.

Month	Daily Fecal Coliform Loads to Landuse Type/PERLND # (cfu/acre*day)							Total (cfu/ acre*day)
	Forest	Pasture 1	Pasture 2	Farmstead	Rural Res	Cropland	Urban	
	301	302	303	304	305	306	307	
January	4.28E+06	2.53E+09	5.05E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.11E+10
February	4.28E+06	2.53E+09	5.05E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.11E+10
March	4.28E+06	2.51E+09	5.03E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.11E+10
April	4.28E+06	2.50E+09	5.00E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.11E+10
May	4.28E+06	2.50E+09	5.00E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.11E+10
June	4.28E+06	2.49E+09	4.98E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.10E+10
July	4.28E+06	2.49E+09	4.98E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.10E+10
August	4.28E+06	2.49E+09	4.98E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.11E+10
September	4.28E+06	2.50E+09	5.00E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.11E+10
October	4.28E+06	2.51E+09	5.03E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.11E+10
November	4.28E+06	2.51E+09	5.03E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.11E+10
December	4.28E+06	2.53E+09	5.05E+09	1.77E+09	1.77E+09	3.38E+06	0.00E+00	1.11E+10

Table F.3. Daily nonpoint fecal colifom loadings to subwatershed East per acre of landuse.

Month	Daily Fecal Coliform Loads to Landuse Type/PERLND # (cfu/acre*day)							Total (cfu/ acre*day)
	Forest 101	Pasture 1 102	Pasture 2 103	Farmstead 104	Rural Res 105	Cropland 106	Urban 107	
January	4.24E+06	4.13E+09	8.26E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.62E+10
February	4.24E+06	4.13E+09	8.26E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.62E+10
March	4.24E+06	4.11E+09	8.22E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.61E+10
April	4.24E+06	4.09E+09	8.18E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.61E+10
May	4.24E+06	4.09E+09	8.18E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.61E+10
June	4.24E+06	4.07E+09	8.15E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.60E+10
July	4.24E+06	4.07E+09	8.15E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.60E+10
August	4.24E+06	4.07E+09	8.15E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.60E+10
September	4.24E+06	4.09E+09	8.18E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.61E+10
October	4.24E+06	4.11E+09	8.22E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.61E+10
November	4.24E+06	4.11E+09	8.22E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.61E+10
December	4.24E+06	4.13E+09	8.26E+09	1.89E+09	1.89E+09	3.28E+06	0.00E+00	1.62E+10

Table F.4. Daily nonpoint fecal coliform loadings to subwatershed West1 per acre of landuse.

Month	Daily Fecal Coliform Loads to Landuse Type/PERLND # (cfu/acre*day)							Total (cfu/ acre*day)
	Forest 101	Pasture 1 102	Pasture 2 103	Farmstead 104	Rural Res 105	Cropland 106	Urban 107	
January	4.24E+06	4.01E+09	8.02E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.69E+10
February	4.24E+06	4.01E+09	8.02E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.69E+10
March	4.24E+06	3.99E+09	7.98E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.69E+10
April	4.24E+06	3.98E+09	7.95E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.68E+10
May	4.24E+06	3.98E+09	7.95E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.68E+10
June	4.24E+06	3.96E+09	7.91E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.67E+10
July	4.24E+06	3.96E+09	7.91E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.67E+10
August	4.24E+06	3.96E+09	7.91E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.67E+10
September	4.24E+06	3.98E+09	7.95E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.68E+10
October	4.24E+06	3.99E+09	7.98E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.69E+10
November	4.24E+06	3.99E+09	7.98E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.69E+10
December	4.24E+06	4.01E+09	8.02E+09	2.44E+09	2.44E+09	0.00E+00	0.00E+00	1.69E+10

Table F.5. Daily nonpoint fecal coliform loadings to subwatershed West2 per acre of landuse.

Month	Daily Fecal Coliform Loads to Landuse Type/PERLND # (cfu/acre*day)							Total (cfu/ acre*day)
	Forest	Pasture 1	Pasture 2	Farmstead	Rural Res	Cropland	Urban	
	101	102	103	104	105	106	107	
January	4.24E+06	4.43E+09	8.85E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.64E+10
February	4.24E+06	4.43E+09	8.85E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.64E+10
March	4.24E+06	4.41E+09	8.82E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.63E+10
April	4.24E+06	4.40E+09	8.79E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.63E+10
May	4.24E+06	4.40E+09	8.79E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.63E+10
June	4.24E+06	4.38E+09	8.76E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.62E+10
July	4.24E+06	4.38E+09	8.76E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.62E+10
August	4.24E+06	4.38E+09	8.76E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.62E+10
September	4.24E+06	4.40E+09	8.79E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.63E+10
October	4.24E+06	4.41E+09	8.82E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.63E+10
November	4.24E+06	4.41E+09	8.82E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.63E+10
December	4.24E+06	4.43E+09	8.85E+09	1.55E+09	1.55E+09	3.28E+06	0.00E+00	1.64E+10

APPENDIX G. GKY&A's RESPONSES TO USEPA's PRELIMINARY COMMENTS ON THE FECAL COLIFORM TMDL FOR THUMB RUN

(Responses are in italics)

1. Executive Summary, This section states "The stage I allocation requires a 100% reductions in direct loads from the straight pipe." The report mentions that there were no straight pipes, but one septic tank was modeled as such because of its proximity to the stream. The term "straight pipe" should be amended or clarified.

The term "straight pipe" was changed to "direct load from failing septic systems."

2. Section 1.2, Please provide the violation rate associated with the 1998 and 2000 assessment periods.

There was a 47% violation rate for the 1998 assessment period and 40% violation rate for the 2000 assessment period. This information was added to Section 1.2.

3. Please spell out all acronyms on their initial use.

This has been corrected.

4. Page 1-3, Please change the first statement to state "... for a higher sampling frequency the geometric mean criterion is applied." Please change the second statement in Section 1.3.1 to "In some of the streams, ... wildlife alone ..." Please cite the TMDLs that document this phenomena and state whether this is based on modeling or data. Please provide a reference (the public meeting) for the statement "people do not swim in the stream".

These statements were provided by VADEQ. VADEQ is conversing with EPA, and the language will be revised accordingly after an agreement on appropriate language has been made.

5. Page 1-4, Please mention that the statement "... the removal of all sources of fecal coliform (other than wildlife) does not allow the stream to attain standards." is based on modeling. Please remove the last statement "or any other federal and state water quality management program." from this and any other report.

Please refer to the response for comment 4.

6. Page 2-1, Is the distance from the confluence of the east and west branch to the confluence with the Rappahanock 7.1 or 7.4 miles?

The distance from the East and West Branches to the confluence with the Rappahannock is 7.4 miles. This correction has been made in Section 2.1.

7. Page 2-2, Please elaborate on the soils section, describe the parent materials. The second sentence of section 2.2 should state "These soils are ..." Is The Plains 2 NNE a weather station?

More detailed information on soils in the watershed was obtained, but not included in the report because it was not considered in the model development. Soils around site one consists of Perciville Tinkerville Complex, Middleburg Loam, and rocky units. Soils around site 2 are very rocky and consist of Cotter's Loam, and more sand and silt and less clay. The soils around site 3 are mostly Cotter's Loam. All soils in the watershed are considered to be well drained, and this is referenced in Section 2.2

The second sentence of Section 2.2 has been corrected.

The Plains 2 NNE is a National Weather Service cooperative station, as referenced in the first sentence of Section 2.3.

8. Page 2-5, Please mention that two of the three RRRC sampling locations were not associated with DEQ monitoring stations.

I believe this is clear from Figure 2.5 and Section 2.6.2.

9. Page 2-7, Can we compare the sampling data with precipitation? Does Figure 2.6 document all of the DEQ sampling, the executive summary states that there were 30 samples taken by DEQ (15 for the 1998 assessment and 15 for the 2000 assessment).

DEQ does not record precipitation data in conjunction with sampling, so there is no precipitation data within the watershed to compare the data to. Figure 2.6 does not document all of the DEQ sampling data, only the data used to list the stream as impaired, as referenced in Section 2.6.l.

10. Page 2-9, Can we split the violation rate between high and low flow events?

Table 2.3 has been updated to list "dry" and "wet" violations independently. I would also like to note that while the instantaneous measurements show higher violations of the instantaneous standard during the "wet" periods, our conclusions show that reducing loadings during "dry" periods is more significant to meet the geometric mean standard.

11. Page 3.1, Mentions that the WWTP was replaced by a septic system. How many people were served by the WWTP and how many are served by the new septic system?

DEQ obtained all available information on the wastewater treatment plant. The old WWTP, now the septic system, serves a camp site, and the user capacity is considered to be unchanged.

12. Page 3-2, The report has 100 hounds under the livestock category. Is there a dog breeder in the watershed? Are these hounds different from the pets referred to later in the section?

There is a kennel in the watershed, as referenced in Section 3.2.1. The hounds from this kennel are considered separately from pets.

13. Page 3-3, Are the horses modeled as going to the stream? Horses have not been modeled this way in the past.

Based on the number of horses in the watershed (200), observations of horse pastures with stream access, and public encouragement, horses were modeled to contribute direct loads to the stream. The stream access time for horses is referred to in Section 3.2.1.

14. Page 3-4, Was the number of septic systems determined by dividing the census derived population (880) by the average people per home (2.75)? Was there any verification of this via ground truthing or counting the homes on USGS quadrangles? Did a failing septic system have to be within 50 feet of a stream bank to be considered as a source? Were all failed septic systems (other than the one referred to as a straight pipe) treated as wet weather nonpoint sources? If these failed septic systems are within 50 feet of the stream could their loading be transported to the stream via lateral flow?

Yes, the septic systems were determined by dividing the 2000 Census population by the average occupancy rate and assuming that all residences have a septic system, as referenced in Section 3.2.2. These numbers were verified by checking E-911 records for residences within the watershed (GIS *polygons were clipped in ArcView). They were also verified by counting mailboxes during a windshield survey, as referenced in Section 3.2.2. This discussion of septic system number verification has been expanded in Section 3.2.2.*

Yes, a failing septic system has to be within 50 feet of a stream to be considered as a source and all failing septic systems, except for one, were treated as wet weather nonpoint sources. Yes, the loading from failing septic systems could be transported via lateral flow, but this was not accounted for in the model because it was considered insignificant.

15. Page 3-6, Please include all the wildlife densities. In Table 3.5, the goose and muskrat populations should be 705 and 65 respectively and the animal units for deer and turkey should be 170 and 2 respectively.

The densities for bear and fox were calculated from the given population divided by the suitable habitat. This information was added to the list in Section 3.2.3. Due to rounding, some of the numbers in tables 3.5 and 3.6 do not add up. A note of this possibility has been added before both tables. The population of turkey is inaccurate in Table 3.5, it should be 106 (with a population density of 0.01) and the population of bear is inaccurate in Table 3.6, it should be 10. These corrections have been made.

16. Page 3-7, In Table 3.6 the total for Turkey and bear should be 202 and 10 respectively. In Table 3.7, can we document the number of animals discharging directly to the stream. Are cats and dogs given the same loading under pets? Should dogs be given the same loading as hounds?

Please see the response to comment 15. The numbers of animals discharging directly to the stream are provided in the loading spreadsheets.

Cats and dogs are considered to be the only significant pets in the watershed, and their loading is combined (Geldreich et al., 1978). The loadings for hounds and pets are considered separately (see Table 3.9).

17. Page 3-8, Table 3.8 Please change the second column to "% of total Rural Residential and Farmstead Landuse in Subwatershed" since we are giving the amount of rural residential and farmstead land in the subwatershed as compared to rural residential and farmstead land in the entire watershed. Why were biosolids modeled as a point source being they are land applied and wet weather driven? Please

check the spelling of "tool" in the second sentence of section 3.3. Please amend the first sentence in the second paragraph of section 3.3 to state "... suspected sources of fecal coliform in Thumb Run ...."

Table 3.8 has been modified as suggested.

Because there was only one biosolids application during the water quality calibration time period, it was modeled as a direct source on the date of the first significant storm after the application, as referred to in Section 3.2.5 and 4.4.1.4.1. This methodology takes into account that the biosolids are land applied and wet weather driven. In this watershed, there was not enough biosolids to consider modeling them as land applied manure.

The spelling of "tool" in Section 3.3 has been corrected.

The first sentence in the second paragraph of Section 3.3 has been amended.

18. Page 4-5, Please explain why the Piedmont weather station was used in the calibration of Battle Run since it is the furthest away.

Precipitation data from various weather stations was evaluated, and Piedmont had one of the most complete records of data for the calibration time period and the highest correlation to Battle Run flow. This explanation is provided in Section 4.3.1.

19. Page 4-9, Figures 4.5 and 4.6 lead the reader to believe that the model is under representing the flows below 10 cfs. Please verify as to whether this is true and provide some possible reasons.

Yes the model is under representing the baseflows, but the undersimulation is within acceptable criteria, as described in Section 4.3.2.

20. Page 4-11, See comment 19.

An explanation of why the baseflow is under represented during the validation time period is provided in Section 4.3.3.

21. Page 4-13, In Table 4.5 please document the percent impervious land. How far is Dulles Airport from Thumb Run?

The percent impervious land for each landuse is provided in Table 2.1. Dulles Airport is approximately thirty miles east of the Thumb Run watershed. This information has been added to Section 4.4.1.2.

22. Page 4-15, What is practice code WP-2? Section 4.4.1.4, mentions that there are point sources, based on the report there are no active point sources.

WP-2 is the code for stream protection, not WP-1 as listed in table 4.6. This typo in the table has been corrected.

Loading from the Camp Moss Hollow WWTP, a point source, was accounted for in the model because the exact date that it was taken off line was not known. This is referenced in Section 4.4.1.4.1. The first sentence in Section 4.4.1.4 was amended to read, "..sources of fecal coliform accounted for in the model of the Thumb Run watershed."

23. Page 4-16, Please discuss why biosolids were modeled as a point source. Please clarify the term "straight pipe".

Please see the response to comment 17. There is an estimated direct load from one failing septic system due to a residence's proximity to the stream (see Section 3.2.2). This was modeled as a straight pipe.

24. Page 4-19, The word "To" in the third sentence of the second paragraph under the bullets needs to be amended.

This has been corrected.

25. Figures 4.12 though 4.15, Is the model under representing the peak fecal coliform concentrations?

The model is not considered to be under representing the peak fecal coliform concentrations. Some observed high concentrations were not simulated, likely due to missed storm events not included in the precipitation dataset. This is discussed in the last paragraph of Section 4.4.3.

26. Page 5-1, Please change the first sentence in the second paragraph to state "... HSPF water quality model to the 30-day..." In section 5.1 the geometric mean standard is shown in Figure 5.1 and the instantaneous is shown in Figure 5.2.

These corrections have been made.

27. Page 5-2, Figure 5.1 There is no change exhibited in the geometric mean when direct source and nonpoint source loadings are added is this because the standard is already violated 100% of the time? Please change point source to direct deposit nonpoint sources.

Yes, the 30-day geometric mean is violated nearly 100% of the time, as shown in Figure 5.3. The reference to "point" source has been changed to "direct" source and "nonpoint" source has been changed to "land based" source.

28. Page 5-4, Has the permit for Camp Moss Hollow WWTP expired? Please change the term "straight pipe".

Yes, the Camp Moss Hollow WWTP's permit expired on September 30, 2001, as referenced in Section 3.1. The term straight pipe has been amended.